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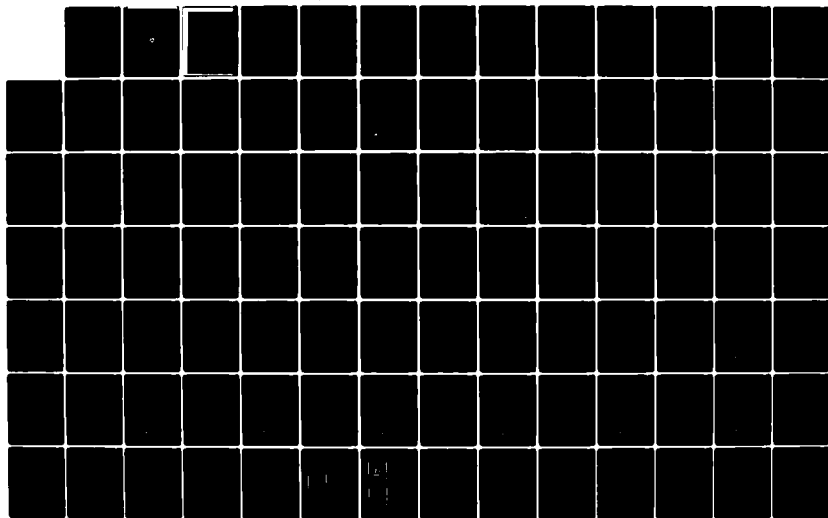
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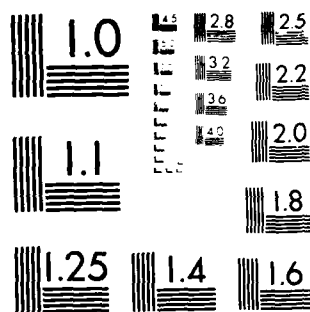
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AD-A148 366

AIDS TO NAVIGATION SRA SUPPLEMENTAL EXPERIMENT
PRINCIPAL FINDINGS:
PERFORMANCE OF SHORT RANGE AIDS UNDER
VARIED SHIPHANDLING CONDITIONS

Eclectech Associates Division of
Ship Analytics, Incorporated
North Stonington Professional Center
North Stonington, Connecticut 06359



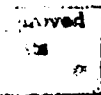
September 1984

Interim Report

Prepared for

U.S. Coast Guard
U.S. Department of Transportation
Office of Research and Development
Washington, D.C. 20593

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The authors also wish to express their gratitude to the Northeast Marine Pilots, Incorporated, of Newport, Rhode Island who served as consultants and subjects in the experiment. We especially wish to thank Captain Kenneth Warner, president of the Association, and Captain John Neary, Jr. who served as presimulation consultant. We also wish to thank Captain Michael Ball, Captain Donald Church, Captain Arthur Duffy, Captain Vernon Dunlap, Captain Walter Fricke, Captain John Hadley, Captain Robert Larson, and Captain David Leonard. These pilots served as experimental subjects, and they made valuable comments on the piloting process as it contributed to the experimental findings.

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PREFACE

The objective of the United States Coast Guard's Performance of Aids to Navigation Systems project is to prepare guidelines for the design and evaluation of aid systems in restricted waterways. The Coast Guard's interest includes fixed and floating visual aids, radar, and radio aids. To provide quantitative data on which to base these guidelines, a series of experiments was done on two simulators, the Maritime Administration's Computer Aided Operation Research Facility (CAORF) at Kings Point, New York and a simulator developed for the project at Ship Analytics, Incorporated in North Stonington, Connecticut.

In 1982 at an interim point in the project, a draft manual was published summarizing completed components on the performance of visual and radio aids in a form useful as guidelines. "Draft SRA/RA Systems Design Manual for Restricted Waterways" is available from NTIS as AD-A113236.

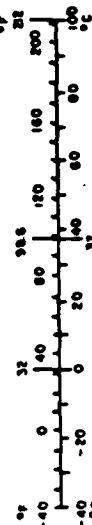
The project is ongoing. The present phase of the work has included new simulator experiments on the effectiveness of turnmarkings for nighttime piloting and on the effectiveness of short-range aids (buoys) for radar piloting, on the effect of shiphhandling factors on pilot performance. The present report discusses the effect that shiphhandling factors have on pilot performance. A future experiment is planned investigating the special needs of the meeting traffic situation.

The continuing project includes two additional components meant to maximize the transfer of the findings to sea. To validate the USCG/SA simulator on which most of the experiments were run, ship track data was collected in Chesapeake and Narragansett Bays. A report comparing these data to simulator data was recently completed. A model implementation is in progress in Narragansett Bay. The validation data is a sample of performance at sea under present markings. After the markings are changed, ship track data will be collected again as a test of the manual evaluation.

A final SRA/RA design manual incorporating new data and experiment with the draft manual is planned for 1985.

METRIC CONVERSION FACTORS

| Approximate Conversions from Metric Measures | | | |
|----------------------------------------------|------------------------|------------------------|-----------------|
| When You Know | Multiply by | To Find | Symbol |
| LENGTH | | | |
| millimeters | 0.04 | inches | in |
| centimeters | 0.4 | inches | in |
| meters | 3.3 | feet | ft |
| kilometers | 1.1 | miles | mi |
| kilometers | 0.6 | miles | mi |
| AREA | | | |
| square centimeters | 0.16 | square inches | in ² |
| square meters | 1.2 | square yards | yd ² |
| square kilometers | 0.4 | square miles | mi ² |
| hectares (10,000 m ²) | 2.5 | acres | ac |
| MASS (weight) | | | |
| grams | 0.035 | ounces | oz |
| kilograms | 2.2 | pounds | lb |
| tonnes (1000 kg) | 1.1 | short tons | ton |
| VOLUME | | | |
| milliliters | 0.03 | fluid ounces | fl oz |
| liters | 2.1 | pints | pt |
| liters | 1.06 | quarts | qt |
| liters | 0.26 | gallons | gal |
| cubic meters | 35 | cubic feet | ft ³ |
| cubic meters | 1.3 | cubic yards | yd ³ |
| TEMPERATURE (exact) | | | |
| Celsius temperature | 5/9 (then add 32) | Fahrenheit temperature | °F |
| Fahrenheit temperature | 5/9 (then subtract 32) | Celsius temperature | °C |



| Approximate Conversions to Metric Measures | | | |
|--------------------------------------------|------------------------|---------------------|-----------------|
| When You Know | Multiply by | To Find | Symbol |
| LENGTH | | | |
| inches | 2.5 | centimeters | cm |
| feet | 30 | centimeters | cm |
| yards | 0.9 | meters | m |
| miles | 1.6 | kilometers | km |
| AREA | | | |
| square inches | 6.5 | square centimeters | cm ² |
| square feet | 0.09 | square meters | m ² |
| square yards | 0.8 | square meters | m ² |
| square miles | 2.6 | square kilometers | km ² |
| acres | 0.4 | hectares | ha |
| MASS (weight) | | | |
| ounces | 28 | grams | g |
| pounds | 0.45 | kilograms | kg |
| short tons (2000 lb) | 0.9 | tonnes | t |
| VOLUME | | | |
| teaspoons | 5 | milliliters | ml |
| tablespoons | 15 | milliliters | ml |
| fluid ounces | 30 | milliliters | ml |
| cups | 0.24 | liters | l |
| pints | 0.47 | liters | l |
| quarts | 0.95 | liters | l |
| gallons | 3.8 | liters | l |
| cubic feet | 0.03 | cubic meters | m ³ |
| cubic yards | 0.76 | cubic meters | m ³ |
| TEMPERATURE (exact) | | | |
| Fahrenheit temperature | 5/9 (then subtract 32) | Celsius temperature | °C |

* 1 in. = 2.54 centimeters. For other exact conversions and more data, see tables, see NBS Misc. Publ. 706, Units of Weights and Measures, NBS 82-35, 50 Catalog No. C13.10.706.

EXECUTIVE SUMMARY

INTRODUCTION

The purpose of the Performance of Aids to Navigation (AN) Systems Project is to provide quantitative evaluations by simulator of the performance of aid arrangements under a variety of environmental conditions, ship characteristics, and channel dimensions. The SRA/RA manual of 1982 treated the performance of aid arrangements as discrete events, indexed by the crosstrack mean and standard deviation observed for the set of transits. The variables evaluated by the project included several quantitative variables whose primary effects are on the shiphandling components of the piloting task: these are ship size, ship speed, and channel width. The SRA/RA manual used the available data on these variables to provide "correction factors" that allowed interpolation of simulator findings to extend the findings to conditions not included.

The primary purpose of the present experiment is to evaluate conditions that would refine these correction factors. For this reason the emphasis in this experiment is on shiphandling, rather than on aid arrangements. The findings described below are based on both old and new data.

SHIP SIZE

Ship size and ship maneuverability have been identified in past experiments as a major variable with large effects on performance and risk. New conditions were included in the present experiment to increase the available data. A 52,000 dwt ship was evaluated as an intermediate point between the 30,000 and 80,000 dwt ships used in earlier experiments. In preparation for the development of the correction factors, the ship size effect was re-evaluated at both high and low levels of buoy density. Conditions were compared using a variety of measures including (1) simulated sea trials or offline runs, (2) means and standard deviations, and (3) relative risk factors. A subordinate purpose of the analysis was a further understanding of the relationship among performance measures.

- The three ships were evaluated by simulated sea trials: turning circles and Z-maneuvers. This evaluation of "inherent controllability" was part of a continuing search for a ship dimension that would predict "piloted controllability" in the experimental scenarios better than does deadweight tonnage. However, piloted performance was best predicted by deadweight tonnage. For this project's present needs, that remains the best dimension to describe ship size.
- Piloted performance observed on the simulator showed the 52,000 dwt ship's performance fell between the 30,000 and 80,000 dwt ship under the low buoy density conditions as indexed by the mean and standard deviation. Performance improved as buoy density increased. The interaction of ship size and buoy density was such that ship size had the larger effect. Piloted performance was poorer for the larger ship whatever the aid arrangement.

- Piloted performance observed on the simulator is incompletely measured by the cross-rack mean and standard deviation of the set of transits. Performance can be re-interpreted as "risk" on this simulator when ship and channel dimensions are considered as well. The relative risk factor is an index that allows consideration of all these factors. The consideration of a variety of factors makes this index the most appropriate performance measure for comparing a variety of conditions across a number of experiments.

SHIP SPEED

Before this experiment, the effects of ship speed on performance and risk were uncertain. From the results of the simulated sea trials and from the opinions of the pilots, performance was expected to improve and risk was expected to be less at the higher speed of 10 knots. However, piloted performance in an earlier experiment on the simulator had shown a deterioration in performance and an increase in risk with the high speed. New conditions were evaluated to extend the speed comparison to the new 52,000 dwt ship and to investigate the possibility that the effect of ship speed might depend on buoy density.

- Under low buoy density with all three ships, the effect of speed on risk was small and inconsistent. It was concluded that a correction factor for this effect is not necessary or appropriate.
- Under high buoy density with the 80,000 dwt ship, there is a marked decrease in risk with an increase in speed from 6 to 10 knots. It was concluded that speed improves performance or lessens risk in restricted waterways only under buoy densities that allow the pilot to give optimal control orders. Such conditions cannot reliably be expected at sea and should not be the basis of a correction factor.

CHANNEL WIDTH

The SRA/RA manual used a channel width correction factor based on the relative performance of the 30,000 dwt ship evaluated in 500- and 800-foot channels. This correction factor was applied to available performance data on the 80,000 dwt ship in the 500-foot channel to derive a value for the 80,000 dwt ship in the 800-foot channel -- or for larger ships in larger channels. This experiment evaluated the 80,000 dwt ship in the 800-foot channel to test this derivation.

- Performance for the 30,000 dwt ship deteriorated in precision as indexed by the mean and standard deviation with the larger channel width. Possibly the small bow in the wide channel does not provide an adequate reference for judging the ship's position; possibly the pilots are less cautious with a small ship in a wide channel. The larger channel width results in a decrease in risk for the 30,000 dwt ship. Because of the decrease in precision, the decrease in risk was not as great as was expected.
- Performance of the 80,000 dwt ship deteriorates slightly in precision as indexed by the mean and standard deviation. Therefore, the

observed decrease in risk for the larger ship as channel width increases is greater than previously derived when based on the performance of the smaller ship.

- The interaction between ship size and channel width showed risk was greater for the larger ship whatever the channel width.

TURN MANEUVER

Earlier experiments identified the turn maneuver as a critical and high-risk event in transiting narrow channels. Earlier experiments also identified several variables as having major effects on the risk involved in the turn. The previously identified variables considered in this experiment were number/ arrangement of turn buoys, ship size, and day/night. The simulator evaluation of a variety of conditions is preferable to interpolation among fewer evaluated conditions.

- Ship size had the major effect on risk during the turn maneuver: risk was higher for the 80,000 dwt ship whatever the number/arrangement of turn buoys, day or night.
- Risk was higher at night. This was despite the pilots' use of a nighttime strategy of turning harder to avoid the uncertain outside edge of the channel. The nighttime strategy was not used for the 80,000 dwt ship, therefore, the measured risk for the 80,000 dwt ship appears high whatever the turnmarking.
- Risk decreased with more buoys. However, it was only with the 30,000 dwt ship that performance was precise and risk was low.
- It was not intended to develop correction factors for performance as a function of turn buoy number because the pilots treat each turn arrangement in a distinctive way. The completeness of the data now available will support aid design and operational decisions without a need for such a correction factor.

DESIGN CONDITIONS

All experiments have been run with difficult shiphandling conditions including slow speed, low underkeel clearance, and crosscurrent and wind on the assumption that only difficult shiphandling conditions would reveal differences in the performance of alternative aid arrangements. Observed performance has supported this assumption. It has also been assumed that the difficult shiphandling conditions build a degree of conservatism into the data and, thus into the manual. One scenario was run with easier shiphandling conditions to test the second assumption.

- Performance was more precise under the easier shiphandling conditions. The difficult shiphandling conditions have built a conservatism and safety margin into the manual because of the low frequency of those difficult environmental or shiphandling events in real world piloting.

CONCLUSION

The SRA/RA manual of 1982 made maximum use of the then-available data. When possible, data on conditions that had been evaluated were extended by interpolation, extrapolation, or generalization. These extensions were made conservatively; if they erred, they erred on the side of caution. This conservatism meant that large numbers of conditions were assessed as having high risk. The new conditions evaluated on the simulator have generally been of lower risk than hypothesized. The result of this experiment is a general decrease in the conservatism of the manual and more distinction among conditions.

TABLE OF CONTENTS

| <u>Section</u> | <u>Title</u> | <u>Page</u> |
|-----------------|--------------------------------------------------------|-------------|
| 1 | INTRODUCTION | 1 |
| 1.1 | Overview of the Aids to Navigation Project | 1 |
| 1.2 | SRA Supplemental Experiment | 2 |
| 1.2.1 | Selection of Experimental Conditions | 2 |
| 1.2.2 | Constant Conditions | 5 |
| 1.2.3 | Subjects and Procedures | 6 |
| 1.2.4 | Performance Requirements | 6 |
| 1.2.5 | Performance Measures | 10 |
| 1.2.6 | The Descriptive Analysis of the Primary Data | 10 |
| 1.2.7 | The Inferential Analysis of the Data | 11 |
| 1.3 | Organization of this Report | 11 |
| 2 | SHIP SIZE DATA | 13 |
| 2.1 | Overview | |
| 2.2 | Ship Size Data and the SRA/RA Manual | 13 |
| 3 | SHIP SPEED DATA | 25 |
| 3.1 | Overview | |
| 3.2 | Ship Speed Data and the SRA/RA Manual | 25 |
| 4 | CHANNEL WIDTH DATA | 33 |
| 4.1 | Overview | 33 |
| 4.2 | Channel Width Data and the SRA/RA Manual | 33 |
| 5 | TURN MANEUVER DATA | 41 |
| 5.1 | Overview | 41 |
| 5.2 | Turn Maneuver Data and the Design Manual | 41 |
| 6 | EFFECT OF DESIGN CONDITIONS | 45 |
| 6.1 | Overview | 45 |
| 6.2 | The Design Condition Evaluation and the SRA/RA Manual | 46 |
| <u>Appendix</u> | | |
| A | CHARACTERISTICS OF THE USCG/SA SIMULATOR | A-1 |
| B | SRA SUPPLEMENTAL EXPERIMENT: INSTRUCTIONS TO THE PILOT | B-1 |
| C | PILOTED PERFORMANCE AS A FUNCTION OF SHIP SIZE | C-1 |
| D | PILOTED PERFORMANCE AS A FUNCTION OF SHIP SPEED | D-1 |
| E | PILOTED PERFORMANCE AS A FUNCTION OF CHANNEL WIDTH | E-1 |
| F | PILOTED PERFORMANCE AS A FUNCTION OF TURNMARKING | F-1 |
| G | EFFECT OF DESIGN CONDITIONS ON PILOTED PERFORMANCE | G-1 |
| H | SHIP SIZE AND INHERENT CONTROLLABILITY | H-1 |
| I | SPEED EFFECTS ON INHERENT CONTROLLABILITY | I-1 |
| J | SHIP RESPONSE DATA FOR THE 52,000 DWT SHIP | J-1 |

BIBLIOGRAPHY

LIST OF ILLUSTRATIONS

| <u>Figure</u> | <u>Title</u> | <u>Page</u> |
|---------------|--------------------------------------------------------------|-------------|
| 1 | Performance Requirements and Wind and Current Effects | 7 |
| 2 | Data Collection Lines | 8 |
| 3 | Descriptive Analysis of Crosstrack Action | 9 |
| 4 | Baseline Values for Mean and Standard Deviation, Turn Region | 14 |
| 5 | Ship Size Correction Factors for Turn Regions | 15 |
| 6 | Sample Calculation for Relative Risk Factor | 21 |
| 7 | Relative Risk at Turn Pullout for Ship Size | 23 |
| 8 | Ship Speed Correction Factors for Turn Regions | 26 |
| 9 | Relative Risk at Turn Pullout for Ship Speed | 31 |
| 10 | Channel Width Correction Factors for Turn Regions | 34 |
| 11 | Risk in the Turn Pullout for Ship Size and Channel Width | 39 |

LIST OF TABLES

| <u>Table</u> | <u>Title</u> | <u>Page</u> |
|--------------|-------------------------------------------------------------------|-------------|
| 1 | Experimental Conditions | 3 |
| 2 | Selected Scenario Comparisons | 4 |
| 3 | Effect of Ship Size and Turn (Pullout) Performance | 16 |
| 4 | Ship Size and Recovery Performance | 17 |
| 5 | Ship Size and Trackkeeping Performance | 18 |
| 6 | Ship Speed and Turn (Pullout) Performance | 27 |
| 7 | Ship Speed and Recovery Performance | 28 |
| 8 | Ship Speed and Trackkeeping Performance | 29 |
| 9 | Channel Width Conditions | 34 |
| 10 | Channel Width and Turn (Pullout) Performance | 35 |
| 11 | Channel Width and Recovery Performance | 36 |
| 12 | Channel Width and Trackkeeping Performance | 37 |
| 13 | Prediction of Risk for the 80,000 dwt Ship in an 800-Foot Channel | 38 |
| 14 | Pullout Performance for Turnmarking, Ship Size, and Day/Night | 43 |
| 15 | Design Conditions and Turn (Pullout) Performance | 47 |
| 16 | Design Conditions and Recovery Performance | 48 |
| 17 | Design Conditions and Trackkeeping Performance | 49 |

Section 1 INTRODUCTION

1.1 OVERVIEW OF THE AIDS TO NAVIGATION PROJECT

The United States Coast Guard is responsible for safety in U.S. harbors and channels and, therefore, for the aids to navigation to ensure that safety. The Coast Guard is sponsoring a simulator-based research program to evaluate the effectiveness of aids to navigation as part of their responsibility. Their interests include visual aids, radar, and radio aids. Most of the research has been conducted at a simulator designed and built for the project at Ship Analytics, Inc. in North Stonington, Connecticut. The simulator is described in this report in Appendix A.

The project is ongoing so at an interim point, the available experimental data were used to develop the "Draft SRA/RA Manual for Restricted Waterways."¹ The SRA/RA manual considers both Short-Range Aid and Radio Aid Systems. The purpose of the SRA/RA manual was to provide quantitative data for decisionmaking in the design and maintenance of aids to navigation systems. Experiments conducted after the draft SRA/RA manual are designed to extend its domain. These experiments include nighttime visual piloting,² radar piloting,³ validation of the simulator experiments,⁴ and implementation of the draft manual's recommendations.⁵ The experiment reported here further evaluates piloted performance using visual aids to navigation under a variety of conditions. The planning of this experiment is described in the presimulation report.⁶

¹W.R. Bertsche, M.W. Smith, K.L. Marino, and R.B. Cooper. "Draft SRA/RA Systems Manual for Restricted Waterways." CG-D-77-81, U.S. Coast Guard, Washington, D.C., February 1982. NTIS AD-A113236

²J. Multer and M.W. Smith. "Aids to Navigation Turn Lights Principal Findings: Effect of Turn Lighting Characteristics, Buoy Arrangements, and Ship Size on Nighttime Piloting." CG-D-49-82, U.S. Coast Guard, Washington, D.C., February 1983. NTIS AD-A126080

³J. Multer and M.W. Smith. "Aids to Navigation Radar I Principal Findings: Performance in Limited Visibility of Short Range Aids with Passive Reflectors." CG-D-79-83, U.S. Coast Guard, Washington, D.C., June 1983.

⁴G.E. Grant, J.D. Moynehan, and M.W. Smith. "Aids to Navigation Validation Draft Principal Findings Report: Simulation I - Chesapeake Bay." U.S. Coast Guard, Washington, D.C., February 1983.

⁵J.W. Gynther and R.B. Cooper. "At-Sea Data Collection for Prototype Implementation of Aid System Design Guidelines." Technical Memorandum, U.S. Coast Guard, Washington, D.C., April 1982.

⁶K.L. Marino and M.W. Smith. "Aids to Navigation SRA Supplemental Experiment Presimulation Report," Technical Memorandum, U.S. Coast Guard, Washington, D.C., March 1983.

1.2 SRA SUPPLEMENTAL EXPERIMENT

1.2.1 Selection of Experimental Conditions

The purpose of this experiment is to supplement visual experimental data that were used to develop the SRA/RA manual and to further extend it. The experiment is composed of eight scenarios that are summarized by Table 1. The experiment variables are described below.

(1) Ship size. Each transit was made with either a 30,000 dwt vessel with the bridge midships, a 52,000 dwt tanker with the bridge aft, or an 80,000 dwt tanker with the bridge aft.

(2) Ship speed. Each run was made at either 6 or 10 knots.

(3) Channel width. The channel was either 500 or 800 feet wide.

(4) Straight leg channel marking. The buoys marking the straight legs were either gated and spaced at 5/8 nm intervals, gated and spaced at 1-1/4 nm intervals, or staggered and spaced at 1-1/4 nm intervals along one side.

(5) Turnmarkings. The 35-degree turn was marked by either a one-, two-, or three-buoy configuration.

(6) Lighting conditions. Six scenarios were run during the day and two were run at night.

(7) Design conditions. One scenario was run with no wind and current and the remaining scenarios had a wind and current effect which was following in the first leg and off the port quarter in the second leg.

The scenarios will be compared as identified in Table 2 and analyzed to determine the effect of ship size, ship speed, channel width, turnmarking, and design conditions on piloted performance. As can be seen from Table 2, only one comparison is made between scenarios in this experiment, and the other comparisons are made with related scenarios that were evaluated in earlier experiments. On Table 2 and throughout the text, the experiments are abbreviated as follows:

| | |
|------------------|-------|
| SRA Supplemental | - SRA |
| Ship Variables | - SV |
| Turn Light | - TL |
| Radar | - RI |
| One Side | - OS |
| Channel Width | - CW |

Comparing scenarios across experiments is possible because of planned continuity within the project, however, some caution is required. Early in the project a report⁷ documented a large group of variables which were

⁷W.R. Bertsche and R.C. Cook. "Analysis of Visual Navigational Variables and Interactions." U.S. Coast Guard, Washington, D.C., October 1979.

TABLE 1. EXPERIMENTAL CONDITIONS

| Variable | Scenario | Ship Size (dwt) | Ship Speed (knots) | Channel Width (feet) | Buoy Arrangement | Buoy Spacing | Turn Buoys | Lighting | Wind/Current |
|--------------------------------|----------|-----------------|--------------------|----------------------|------------------|--------------|------------|----------|---------------------------------------------------|
| Ship Size And Ship Speed | 11 | 52,000 | 6 | 500 | Staggered | 1-1/4 nm | 1 | Day | 30 knots and gusting/ 1.2 knots and decreasing |
| | 12 | 52,000 | 10 | 500 | Staggered | 1-1/4 nm | 1 | Day | 30 knots and gusting/ 1.2 knots and decreasing |
| | 5 | 80,000 | 10 | 500 | Gated | 5/8 nm | 3 | Day | 30 knots and gusting/ 1.2 knots and decreasing |
| Channel Width | 6 | 80,000 | 6 | 800 | Gated | 1-1/4 nm | 3 | Day | 30 knots and gusting/ 1.2 knots and decreasing |
| Turn Maneuver | 7 | 80,000 | 6 | 500 | Gated | 1-1/4 nm | 2 | Day | 30 knots and gusting/ 1.2 knots and decreasing |
| | 8 | 80,000 | 6 | 500 | Gated | 1-1/4 nm | 3 | Night | 30 knots and gusting/ 1.2 knots and decreasing |
| | 9 | 30,000 | 6 | 500 | Gated | 1-1/4 nm | 1 | Night | 30 knots and gusting/ 1.2 knots and decreasing |
| Design Conditions | 10 | 30,000 | 10 | 500 | Gated | 1-1/4 nm | 3 | Day | None |

TABLE 2. SELECTED SCENARIO COMPARISONS

| Section | Comparison | Scenarios |
|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| 2 | <u>Effect of Ship Size in Low Buoy Density</u> 30,000 vs 52,000 dwt ship 52,000 vs 80,000 dwt ship 80,000 vs 30,000 dwt ship | SV2 vs SRA11 SRA11 vs SV6 SV6 vs SV2 |
| | <u>Effect of Ship Size in High Buoy Density</u> 30,000 vs 80,000 dwt ship | SV5 vs SV7 |
| 3 | <u>Effect of Ship Speed and Ship Size in Low Buoy Density</u> 6 vs 10 knots for 30,000 dwt ship 6 vs 10 knots for 52,000 dwt ship 6 vs 10 knots for 80,000 dwt ship | SV2 vs SV3 SRA11 vs SRA12 SV6 vs SV8 |
| | <u>Effect of Ship Speed and Ship Size in High Buoy Density</u> 6 vs 10 knots for 80,000 dwt ship | SV7 vs SRA5 |
| 4 | <u>Effect of Channel Width on the 30,000 and 80,000 dwt Ships</u> 30,000 dwt ship in 500 vs 800 foot channel 80,000 dwt ship in 500 vs 800 foot channel | CW4 vs CW6 SV7 vs SRA6 |
| | <u>Effect of Ship Size in the 500 Foot and 800 Foot Channels</u> 30,000 vs 80,000 dwt ships in 500 foot channel 30,000 vs 80,000 dwt ships in 800 foot channel | SV5 vs SV7 SRA6 vs CW6 |
| 5 | <u>Effect of the Three-Buoy Turn</u> 80,000 dwt ship, day vs night | SV7 vs SRA8 |
| | <u>Effect of the Two-Buoy Turn</u> 30,000 vs 80,000 dwt ship in day 80,000 dwt ship, day vs night | OS6 vs SRA7 |
| 6 | <u>Effect of the One-Buoy Turn</u> 30,000 dwt ship, day vs night | SV2 vs SRA9 |
| | <u>Effect of Design Conditions</u> Wind/current, 6 knots, 1 foot underkeel clearance vs no wind/current, 10 knots, 10 foot under clearance No wind/current, low visibility and 6 knot ship speed vs high visibility and 10 knot ship speed | SRA10 vs OS1 SRA10 vs RA4 |

expected to affect visual piloting, more variables than can be handled in one experiment. In recognition of this complexity a systems approach was taken. The total simulator-evaluation effort was divided into a series of self-contained experiments that focus on a small, manageable number of variables that may interact with each other. To ensure comparability across the body of data, the experiments were designed to be as similar as possible. They share scenario events, performance requirements, performance measures, subject populations, and often, constant conditions. However, there are differences among experiments. To meet the requirements of each experiment, some changes were made in scenario events, in the visual scene, or in the experimental day. Inevitably, there are context effects (influences from other scenarios in the pilot's day) and differences in pilot mix. As each comparison is made throughout the report, the degree of certainty with which it can be made is discussed.

1.2.2 Constant Conditions

This experiment is unique in the Aids to Navigation Project since its purpose is to supplement data that have previously been collected in five experiments. Since the experiment will evaluate the effects of six different variables, by comparing relevant scenarios from different experiments, there are few constant conditions over all scenarios in this experiment. Instead there are "constant conditions" between scenario comparisons because these conditions are matched to those of previous scenarios to determine the effect of the variable of interest. Therefore, the following sections contain a table listing the "constant conditions" for each variable evaluated. For further details of the constant conditions see the experiment Presimulation Report⁸ and the Eclectech Associates Memorandum to the Coast Guard.⁹

Since all experiment scenarios referenced in this report have been conducted on the SA/USCG bridge simulator, the bridge conditions are identical. The pilot has the following bridge conditions available:

- a helmsman to receive his orders
- a gyrocompass repeater
- an engine order telegraph with the opportunity to change speed in the turn, if desired
- charts of the channel with the course, buoy locations, and wind and current conditions

The visual scene for the scenarios consists of the bow image which appears on the center screen with an eyepoint appropriate for the ship. The buoys within each scenario change in location on the screen in response to the ship's motion and disappear behind the bridgewings just before they pass abeam.

⁸K.L. Marino and M.W. Smith, op. cit.

⁹K.L. Marino and M.W. Smith. "Presimulation Changes to SRA Supplemental Experiment," Memorandum to LT W. Ridley, May 13, 1983.

1.2.3 Subjects and Procedures

Nine subjects were recruited from Northeast Marine Pilots, Inc., Newport, Rhode Island. These pilots have recent at-sea experience on similar ships and in similar channels to that which they experienced on the U.S. Coast Guard/SA simulator, and they all have participated in simulator-based research prior to this experiment. One subject participated in presimulation runs that were used to review the scenarios to minimize or eliminate potential problems. Eight pilots participated in the actual experimental runs which took one day per subject.

Each pilot's day consisted of the following events:

1. The briefing included the prepared "Instructions to the Pilot" which appears as Appendix B.

2. The familiarization runs are meant to familiarize the pilot with the simulator, channel, wind and current, and one of three ships, a 30,000, 52,000, and 80,000 dwt vessel. The familiarization scenarios were run under daytime conditions with gated buoys in the straight segments and four buoys marking the turn as illustrated in Appendix B. The four buoys in the turn are meant to prevent the pilots from fixing on a strategy for a one-, two-, or a three-buoy turn before the experiment begins.

3. The experimental runs followed the same size ship familiarization run. The 30,000 dwt ship familiarization scenario was run first followed by two 30,000 dwt scenarios, the 52,000 dwt ship familiarization scenario was then run followed by two 52,000 dwt scenarios, and finally the 80,000 dwt ship familiarization scenario was followed by four 80,000 dwt ship scenarios. Within each ship size, the "easiest" scenarios were run first. For more details, see the presimulation report.

1.2.4 Performance Requirements

The piloting tasks the subject is instructed to perform are illustrated by Figure 1. The ship was initialized 1.3 nm below the turn and 100 feet right of centerline. At that point there was a following current of 1.2 knots and decreasing and a following wind of 30 knots and gusting. The pilot had time to study the chart and plan a strategy before it was necessary to maneuver. The pilot was instructed to take the ship to the centerline of the first leg. He could then leave the centerline when ready to negotiate the turn by his own strategy, which could include temporarily increasing the engine rpm. As he entered the new leg, the wind and current were on his port quarter. The current had decreased in velocity to 0.75 knots with a crosscurrent component of 0.25 knots. The pilot was asked to bring the ship to the centerline of the new leg. Maintaining the centerline at the beginning of the second leg required a drift angle of approximately 3 degrees, a requirement that decreased as the crosstrack velocity of the current decreased. The wind maintained its average velocity.

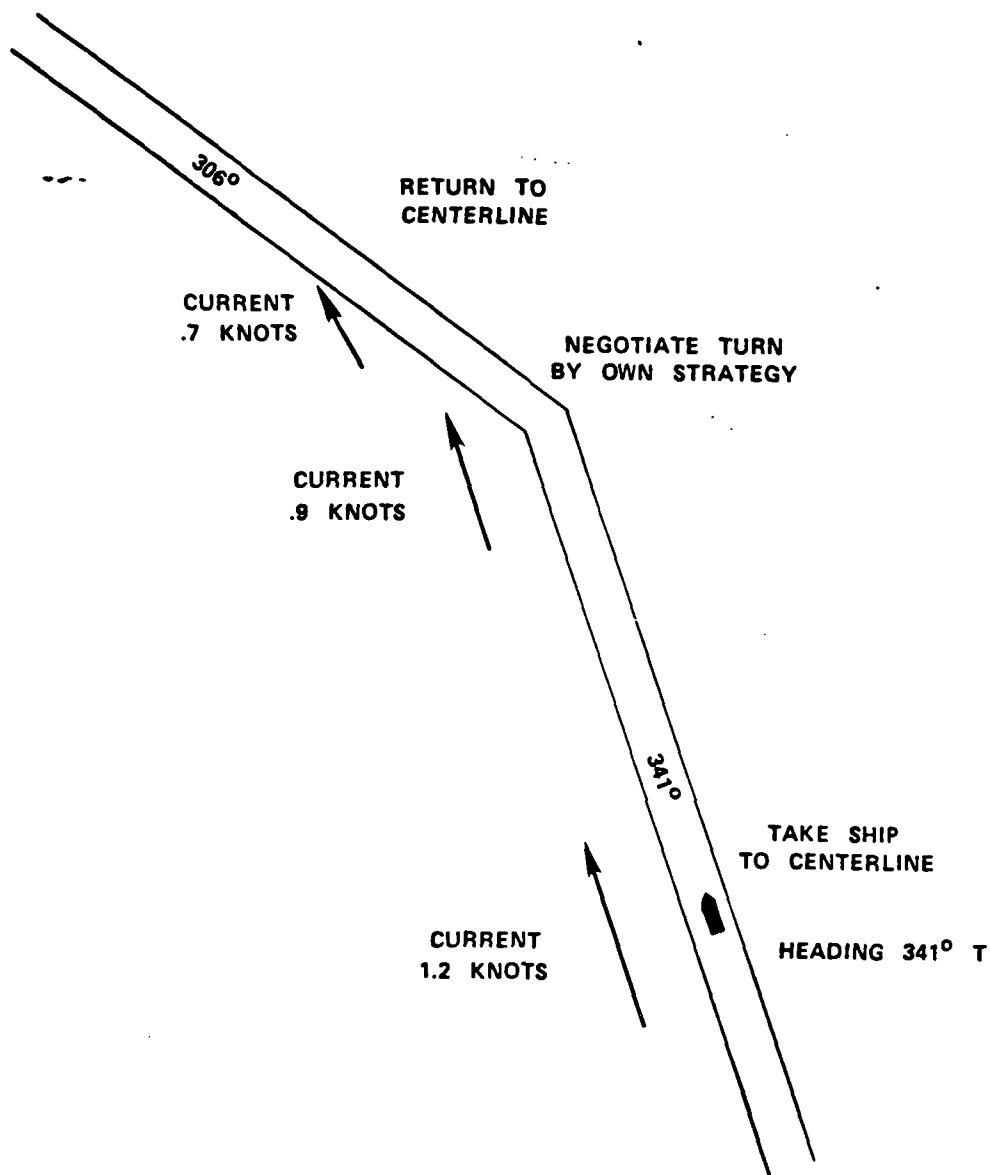


Figure 1. Performance Requirements and Wind and Current Effects

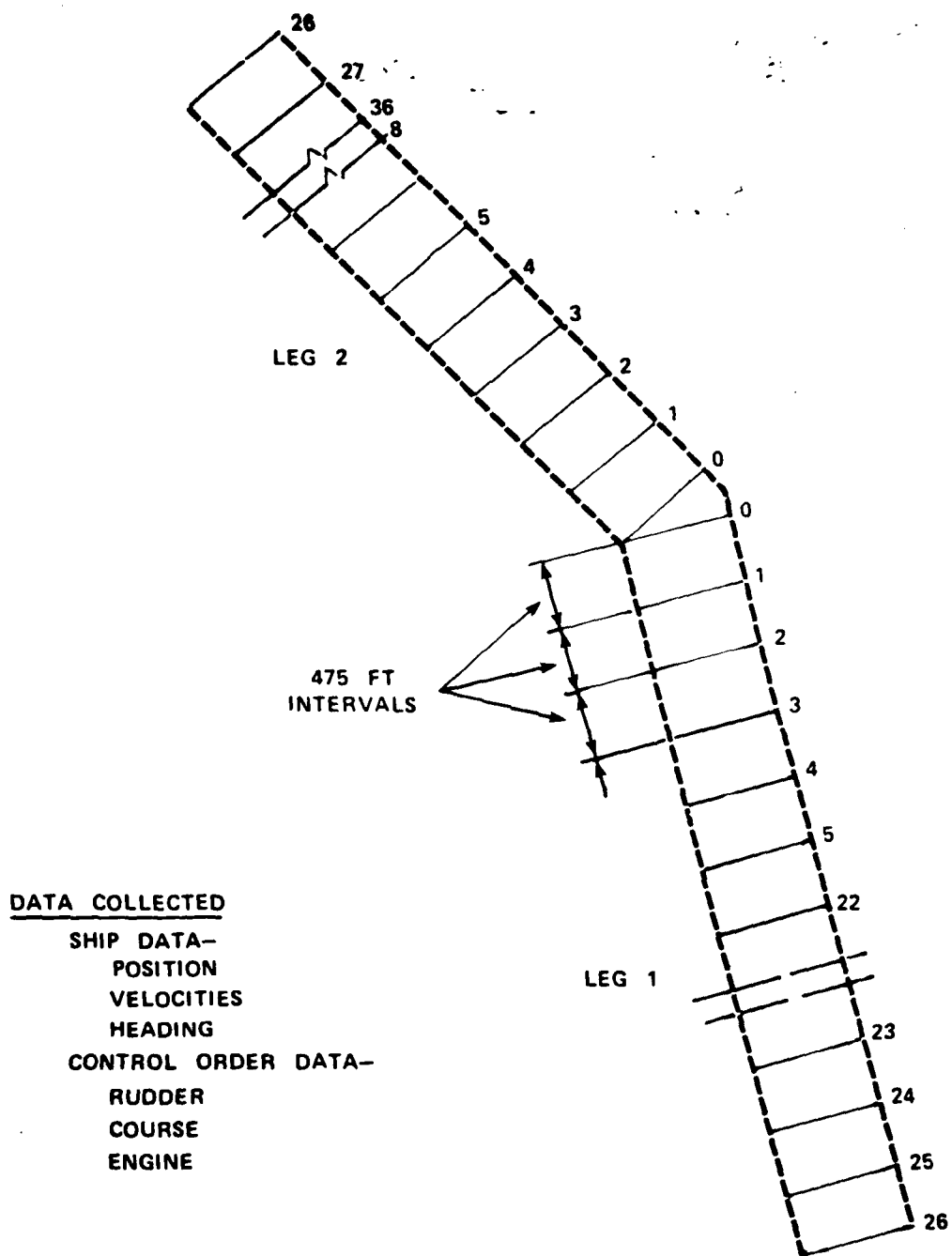


Figure 2. Data Collection Lines

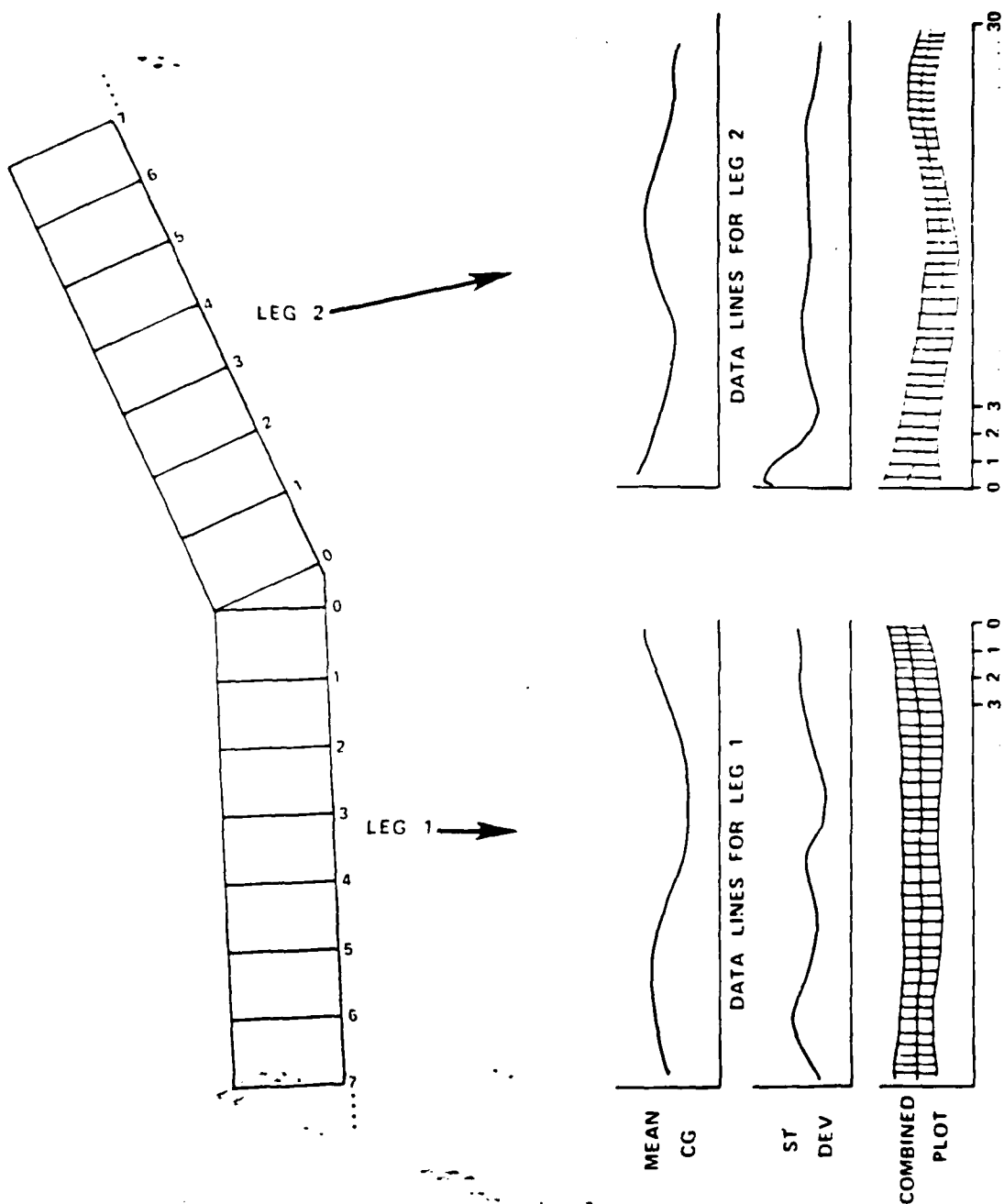


Figure 3. Descriptive Analysis of Crosstrack Action

1.2.5 Performance Measures

A variety of performance measures were collected for use in evaluating the scenario conditions. They included the following classes:

1. The primary measure was the crosstrack position of the ship's center of gravity as a function of alongtrack position during the transit of the channel. When the ship's center of gravity crossed the data lines illustrated in Figure 2, its position was automatically recorded by the computer along with other related measures.

2. The pilot's course, rudder, and engine orders were recorded by an operator at a computer terminal. When they were entered, the computer added measures of ship's status.

3. A postsimulation questionnaire allowed the pilot to comment subjectively on the conditions of each scenario and on his strategies. This questionnaire was the pilot's contribution to the preliminary observation report prepared immediately after the data collection phase.

1.2.6 The Descriptive Analysis of the Primary Data

The principal descriptive analysis is a compilation of data on the position of the ship's center of gravity. The basic measure of its crosstrack position is treated as illustrated in Figure 3. The crosstrack mean and standard deviation of the runs used are calculated at each data line for the set of conditions to be described. The first set of axes shows the means; the second, the standard deviation. On the last set of axes is a "combined plot" which shows the band formed by the mean and two standard deviations to either side of it against the boundaries of the channel. The band encloses 95 percent of expected transits under the experimental conditions sampled. The placement (mean) and width (standard deviation) of this band within the boundaries of the channel are together a quantitative description of the set of transits under these conditions, and, therefore, of the performance of the buoy arrangements.

The trackkeeping portions of the scenario are easiest to interpret. It is assumed that, because of instructions, the pilots are attempting to keep the ship on the designated centerline. The distance of the mean off the centerline and the spread measured by the standard deviations are indications of the performance of the buoy arrangement for the conditions sampled. Therefore, the "best" buoy arrangement is one that puts the mean of the distribution on the trackline and minimizes the standard deviation. Performance in the maneuvering portions is more difficult to interpret. The distribution of crosstrack positions in the maneuvering portions contains the variations in pilots' strategies as well as the performance of the buoys in guiding them in those strategies.

There is an assumption in this discussion that the precision in piloting performance that a buoy arrangement affords is related to the safety of that channel: a safely marked channel is one that results in a distribution of

transits that is well within the channel boundary for both trackkeeping and maneuvering. It should be reemphasized that these measures are derived from an experiment and not a real-world situation. They are measures of performance under the experimental conditions (the experimental design and the simulation) used. For application to real-world channels, they must be considered relative measures of the performance of buoy arrangements or channel conditions. The interpretation of these performance measures as probability of grounding, for example, would be incorrect pending validation of such interpretation in the real world.

1.2.7 The Inferential Analysis of the Data

The selection of the inferential tests to be made required several considerations. The experimental conditions have already been arranged in pairs that are summarized in Table 2. Between these pairs, tests can be made on every data line for an exhaustive exploration of the differences, or critical data lines can be selected to represent scenario events.

Both the mean and standard deviation are needed to describe performance as specified in Section 1.2.6. Tests can be made of either of these statistics. They were made by the procedures which are described in McNemar.¹¹

- When the means from two conditions were compared, a t-test was used.
- The standard deviations of the conditions were compared in pairs dictated by the logic of the experiment. They were compared as variances, using variance ratios, or an F-test.

1.3 ORGANIZATION OF THIS REPORT

Sections 2 through 6 of this report discuss the use of the data pertaining to ship size, ship speed, channel width, turn maneuver, and design conditions for the revised manual. These sections emphasize the development of correction factors and the use of relative risk factors in evaluating piloted performance. Because of the length and complexity of this report, pilot performance data described in Section 1.2 appears in Appendices C through G. (Appendix A describes the simulator where the data were collected, and Appendix B describes the scenarios of the SRA Supplemental Experiment.) The data in Appendices C through G support the development of correction factors and relative risk factors discussed in the text. Inherent ship controllability as a factor in piloted controllability is evaluated in Appendices H, I, and J.

¹¹Q. McNemar. Psychological Statistics, Fourth Edition. John Wiley and Sons, Inc., New York, 1969.

Section 2

SHIP SIZE DATA

2.1 OVERVIEW

One purpose of the SRA Supplemental Experiment was to evaluate new data to determine the effect of ship size and maneuverability on piloted performance in a restricted waterway. Most data previously collected pertained to the 30,000 dwt ship with limited data pertaining to the 80,000 dwt ship, and no experimental data on other size ships. This experiment expanded data relating to ship size by collecting data on an additional ship, a 52,000 dwt tanker.

After conducting this experiment, data is available on piloted performance with three ships (30,000, 52,000, and 80,000 dwt vessels) in two 500-foot channels. One channel is marked with a low buoy density arrangement (staggered buoys and a one-buoy turn), and the other channel is marked with a high buoy density arrangement (short-spaced gated buoys and a three-buoy turn).

A detailed discussion including statistical analyses of performance differences appears in Appendix C. In Appendix C, it was concluded that ship size has a larger effect on piloted performance than buoy arrangement. Overall performance was best with the 30,000 dwt ship, followed closely by the 52,000, and worst with the 80,000 dwt ship regardless of buoy arrangement. However, high buoy density is more accommodating to ship size than low buoy density. A large ship such as the 80,000 dwt ship needs a higher density of buoys merely for adequate performance in entering a channel, exiting a turn, or trackkeeping with crosswind and crosscurrent. In a low buoy density, pilot performance with the 80,000 dwt ship was poor with some ship tracks exiting the channel. With the 30,000 and 52,000 dwt ships pilot performance was satisfactory in both the low and high buoy density channels.

In the draft SRA/RA manual, the importance of ship size was considered in calculating the relative risk factor which identifies the relative probability that the ship will exceed the channel edge during a transit that matches simulated conditions.¹² The data obtained in these comparisons will modify the ship size correction factor used in the revised SRA/RA manual to calculate the relative risk of groundings.

2.2 SHIP SIZE DATA AND THE SRA/RA MANUAL

The 1982 draft SRA/RA manual¹³ treated data from the conditions simulated in the AN experiments in two ways. Some conditions were treated as discrete events to be represented by means and standard deviations observed on the simulator. A table of such data for the critical turn region is reproduced as Figure 4. The primary variable in this table is aid

¹²K.L. Marino and M.W. Smith, op. cit.

¹³Ibid.

LINE: 16 TURN ANGLE

0 TO 20 DEG

20 TO 30 DEG

30 TO 40 DEG

| | | MN : SD | MN : SD | MN : SD |
|-------------------------------------------------------------------------|-------------------|-----------------------------|-------------|------------------------|
| LINE 12: AN DETECTION DISTANCE GREATER THAN 1NM (VISUAL PILOTING) | DAY | LINE 15: AN CONFIGURATION | | |
| | | NON CUTOFF | 3 BUOYS | 22 : 53 |
| | | | 2 BUOYS | DATA NOT YET AVAILABLE |
| | | | 1 BUOY | 40 : 53 |
| | | | HI SENS RNG | 22 : 94 |
| | | | LO SENS RNG | 35 : 139 |
| | | | | 41 : 43 |
| | | | | 59 : 35 |
| | | | | 94 : 38 |
| | | | | 82 : 75 |
| | | | | 123 : 96 |
| | | | | 77 : 132 |
| | | | | 132 : 170 |
| | | | | 121 : 195 |
| | | | | 207 : 251 |
| | NIGHT; DUSK; DAWN | LINE 14: TURN CONFIGURATION | | |
| | | CUTOFF | 3 BUOYS | 81 : 52 |
| | | | 2 BUOYS | DATA NOT YET AVAILABLE |
| | | | 1 BUOY | INADEQUATE |
| | | | HI SENS RNG | 22 : 94 |
| | | | LO SENS RNG | 35 : 139 |
| | | | | 77 : 56 |
| | | | | 73 : 60 |
| | | | | DATA NOT YET AVAILABLE |
| | | | | INADEQUATE |
| | | | | 77 : 132 |
| | | | | 132 : 170 |
| | | | | 121 : 195 |
| | | | | 207 : 251 |
| | DAY | LINE 15: AN CONFIGURATION | | |
| | | NON CUTOFF | 3 BUOYS | 27 : 63 |
| | | | 2 BUOYS | DATA NOT YET AVAILABLE |
| | | | 1 BUOY | 9 : 108 |
| | | | HI SENS RNG | 22 : 94 |
| | | | LO SENS RNG | 35 : 139 |
| | | | | 40 : 76 |
| | | | | 52 : 89 |
| | | | | DATA NOT YET AVAILABLE |
| | | | | 112 : 131 |
| | | | | 215 : 153 |
| | | | | 77 : 132 |
| | | | | 132 : 170 |
| | | | | 121 : 195 |
| | | | | 207 : 251 |
| | NIGHT; DUSK; DAWN | LINE 14: TURN CONFIGURATION | | |
| | | CUTOFF | 3 BUOYS | 46 : 77 |
| | | | 2 BUOYS | DATA NOT YET AVAILABLE |
| | | | 1 BUOY | INADEQUATE |
| | | | HI SENS RNG | 22 : 94 |
| | | | LO SENS RNG | 35 : 139 |
| | | | | 44 : 75 |
| | | | | 42 : 73 |
| | | | | DATA NOT YET AVAILABLE |
| | | | | INADEQUATE |
| | | | | 77 : 132 |
| | | | | 132 : 170 |
| | | | | 121 : 195 |
| | | | | 207 : 251 |



DATA FROM EXPERIMENT



INTERPOLATED VALUES

NOTE: The following terms are not defined in the present text:
 NM nautical mile
 NONCUTOFF an abrupt turn not widened by dredging
 CUTOFF a turn widened to the inside by dredging
 HIGH SENS RNG high sensitivity range
 LO SENS RNG low sensitivity range

Figure 4. Adaptation of figure from 1982 Draft Manual:
 Baseline Values for Mean and Standard Deviation, Turn Region

configuration. Other conditions provided points on the quantitative variables of ship size, ship speed, and channel width. Interpolation on these variables provided "correction factors," multipliers for the tabled data. This treatment extended the original table across ship sizes, ship speeds, and channel widths, increasing the number of conditions to which the manual would be applied. The treatment of ship size in the manual is illustrated in Figure 5.

| SHIP TYPE AND DWT: | MEAN: SHIP CORRECTION FACTOR | STANDARD DEVIATION: CORRECTION FACTOR |
|--------------------|---------------------------------|------------------------------------------|
| | 1.0 | 1.0 |
| | 2.8 | 1.0 |

DWT is deadweight ton.

Figure 5. Adaptation of Figure from 1982 Draft Manual:
Ship Size Correction Factors for Turn Regions

One purpose of the SRA Supplemental Experiment was to refine the critical ship size correction factor by evaluating a third intermediate-sized ship. The original correction factor was a linear interpolation between performance values for the original two ships. In the presimulation report¹⁴ it was hypothesized that the third ship would change the shape of the function. It was also hypothesized¹⁵ that there might be two different ship size functions for high and low buoy density arrangements.

The selected piloted performance data on which the ship size correction factor for the revised design manual will be based are summarized in Tables 3, 4, and 5. The tables follow the draft manual in presenting separate data for turn, recovery, and trackkeeping maneuvers.

¹⁴K.L. Marino and M.W. Smith, *op. cit.*

¹⁵K.L. Marino and M.W. Smith. Memorandum, "Presimulation Changes to SRA Supplemental Experiment," May 13, 1983.

TABLE 3. EFFECT OF SHIP SIZE AND TURN (PULLOUT) PERFORMANCE

| Ship Size (dwt) | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor |
|--------------------|----------|---------------------------------------------|-------------------|------------------------------------|-------------------------|
| | | <u>Low Buoy Density (One Turn Buoy)</u> | | | |
| 30,000 | SV 2 | 3 | 72R | 45 | 0.0068 |
| 52,000 | SRA 11 | 3 | 71R | 54 | 0.0336 |
| 80,000 | SV 6 | 3 | 137R | 65 | 0.3859 |
| | | <u>High Buoy Density (Three Turn Buoys)</u> | | | |
| 30,000 | SV 5 | 3 | 57R | 59 | 0.0162 |
| 80,000 | SV 7 | 3 | 107R | 54 | 0.1841 |
| | | <u>Long-Spaced Gates (Three Turn Buoys)</u> | | | |
| 30,000 | OS 1 | 3 | 59R | 34 | 0.0001 |

¹Means are shown as feet to right or left of centerline.

²Standard deviations are in feet.

TABLE 4. SHIP SIZE AND RECOVERY PERFORMANCE

| Ship Size (dwt) | Scenario | Following Current/Wind (Leg 1) | | | Crosscurrent/Wind (Leg 2) | | | | |
|--------------------------------------------------|----------|--------------------------------|-------------------|------------------------------------|---------------------------|-----------|------|-----------------------|-------------------------|
| | | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor | Data Line | Mean | Standard Deviation | Relative Risk Factor |
| <u>Low Buoy Density (Long-Spaced, Staggered)</u> | | | | | | | | | |
| 30,000 | SV 2 | 22 ³ | 3R | 73 | 0.0044 | 6 | 88R | 60 | 0.0367 |
| 52,000 | SRA 11 | 12 | 45R | 20 | 0.0000 | 12 | 64R | 85 | 0.0827 |
| 80,000 | SV 6 | 20 ³ | 35R | 111 | 0.1081 | 6 | 88R | 63 | 0.0918 |
| <u>High Buoy Density (Short-Spaced, Gates)</u> | | | | | | | | | |
| 30,000 | SV 5 | 22 ³ | 46L | 89 | 0.0366 | 10 | 62R | 72 | 0.0316 |
| 80,000 | SV 7 | 22 ³ | 18L | 109 | 0.0900 | 13 | 25L | 108 | 0.1213 |
| <u>Long-Spaced Gates (Three Turn Buoys)</u> | | | | | | | | | |
| 30,000 | OS 1 | 11 | 20R | 26 | 0.0000 | 8 | 104R | 36 | 0.0055 |

¹Means are shown as feet to right or left of channel centerline.

²Standard deviations are in feet.

³SV Leg 1 performance is not directly comparable to Leg 1 performance in the other experiments.

TABLE 5. SHIP SIZE AND TRACKKEEPING PERFORMANCE

| | | Following Current/Wind (Leg 1) | | | Crosscurrent/Wind (Leg 2) | | | | |
|--------------------------------------------------|----------|--------------------------------|-------------------|------------------------------------|---------------------------|-----------|------|-----------------------|-------------------------|
| Ship Size (dwt) | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor | Data Line | Mean | Standard Deviation | Relative Risk Factor |
| <u>Low Buoy Density (Long-Spaced, Staggered)</u> | | | | | | | | | |
| 30,000 | SV 2 | 15 ³ | 2L | 37 | 0.0000 | 20 | 39R | 73 | 0.0169 |
| 52,000 | SRA 11 | 8 | 19R | 29 | 0.0000 | 19 | 31R | 38 | 0.0000 |
| 80,000 | SV 6 | 15 ³ | 2L | 90 | 0.0371 | 18 | 44L | 50 | 0.0054 |
| <u>High Buoy Density (Short-Spaced, Gates)</u> | | | | | | | | | |
| 30,000 | SV 5 | 15 ³ | 16L | 26 | 0.0000 | 25 | 29R | 30 | 0.0000 |
| 80,000 | SV 7 | 15 ³ | 14L | 43 | 0.0000 | 19 | 17L | 69 | 0.0157 |
| <u>Long-Spaced Gates (Three Turn Buoys)</u> | | | | | | | | | |
| 30,000 | OS 1 | 9 | 13R | 24 | 0.0000 | 18 | 86R | 44 | 0.0064 |

¹Means are shown as feet to right or left of channel centerline.²Standard deviations are in feet.³SV Leg 1 performance is not directly comparable to Leg 1 performance in the other experiments.

Turn is represented by the data line in the pullout at which the mean's crosstrack acceleration approaches zero. This data line has the largest crosstrack displacement and, therefore, the largest risk that can be attributed to the turn. It is usually Data Line 3, approximately two ship lengths beyond the turn apex.

Recovery represents the pilots' efforts to find the desired track and bring the ship to it. A data line between the turn pullout and the mean's approach to centerline with a maximum standard deviation was selected.

Trackkeeping represents the pilots' efforts to maintain the desired track. This definition implies a mean on the desired track, here the centerline, and a minimum standard deviation. This performance was not always achieved in Leg 2. Therefore, a data line that represents the closest approximation to trackkeeping possible under the scenario conditions was selected.

Performance data was selected for the turn recovery and trackkeeping maneuvers. Only the data for the critical turn maneuver presented in Table 3 will be considered here to simplify the discussion. The same general conclusions can be drawn from performance in the other maneuvers. The first block in the table shows performance under low buoy density conditions under which all three ships were run. Ship size seems to have its biggest effect on the mean, rather than on the standard deviation. The means of the distribution of transits for the 30,000 and 52,000 dwt ships are identical, 71 and 72 feet to the right of the centerline, two ship lengths beyond the turn. The mean for the 80,000 dwt ship is almost twice as far off the centerline, 137 feet. These measures do not suggest a linear function for ship size. It is difficult to evaluate the validity of the function they form without other information. It would increase the credibility of the function if it could be related to a ship characteristic other than dead weight tonnage. The length and beam of the three ships increase almost linearly with dead weight tonnage. These dimensions do not determine the shape of function. There is no simple relationship between any obvious measure of maneuverability and this function, as was hypothesized earlier in the project (see Appendix H). It is more likely that performance is determined by scenario events. Possibly the 30,000 dwt ship is handicapped by the midship house; possibly the ship has not completely recovered from the earlier maneuver at the sea buoy in Leg 1. In the second block of the table, the means for the two ships evaluated with high buoy densities show a similar increase: 59 feet for the 30,000 dwt ship and 108 feet for the 80,000 dwt ship. These supplementary data reinforce the direction and magnitude of the difference, but with only two points they make no contribution to the shape of the ship size function. These data support only the general conclusion that performance deteriorates with ship size.

There is a measure available that represents the scenario events more completely than do the mean and standard deviation. The performance measure that is ultimately useful for the SRA/RA manual is the relative risk factor (RRF), the probability that for a given condition (ship size, visibility, etc.) and for given aid arrangements (one, two, or three buoys in the turn), there will be a "grounding". Because this probability is obtained using

performance measured in a simulator experiment, there are certain limits to its use. As an operational definition of this index, a sample calculation for the first cell of Table 3 is presented as Figure 6. The calculation in Figure 6 considers the mean, standard deviation, beam, and channel width to obtain the RRF. This calculation reinterprets performance as "risk". The RRF is discussed more fully in the draft SRA/RA manual.

The means and standard deviations of the set of transits and the ship and channel dimensions were used to calculate the RRFs in the last column of Table 3. The values obtained are plotted in Figure 7. Using the RRF as a measure and considering the low buoy density conditions for which there is data for all three ships, the increase in risk is approximately logarithmic with ship size. While the means are the same for the two smaller ships, the standard deviation increases slightly and the ship length and beam increase. The result is an increase in risk. It is consistent with all earlier findings that there is a logarithmic increase for the 80,000 dwt ship. It is a very large ship for the channel dimensions.

The risk for the 30,000 and 80,000 dwt ship under high buoy density conditions is also plotted. (These are the two points marked by triangles and not connected by a line.) The general placement and slope for that increase in risk is similar to that for the low buoy density conditions. For the high buoy density case, the "risk" for the 30,000 dwt ship is unexpectedly high. It has been observed in several experiments, that given high buoy density and small ship size, the pilots try different tracks through the turn. This increases the standard deviation and the RRF but contributes nothing to the assessment of risk. This paradox is one of the limitations of the RRF as a measure.

A substitute for the high buoy density/small ship case has been included in Table 3 and Figure 7. A scenario from the One-Side Channel Marking Experiment¹⁶ was selected. Like SV 5 it had a three-buoy turn; unlike SV 5 it had long-spaced gates marking the straightaways. With these markings, the pilots are more conservative in the turn pullout and the standard deviation is smaller. The resulting risk is much smaller, as would be expected with a well-marked turn. Such a case is more useful in developing the manual. With this substitution, risk increases with ship size and decreases with buoy density. The interaction indicates there is a large change in risk for the smaller ship as buoy density changes, but much less of a change in risk for the large ship. No increase in buoy density will bring the risk down to small ship levels for a large ship making a hard turn in a narrow channel.

This consideration of the ship size correction factor for the mean in the turn pullout maneuver illustrates the general procedure for developing useful correction factors. The mean (or the standard deviation)-alone is an incomplete performance measure whose validity or usefulness is difficult to evaluate in isolation. Only by considering it in the context of RRFs for a

¹⁶K.L. Marino, M.W. Smith, and V.R. Bertsche. "Aids to Navigation Principal Findings Report: The Effect of One-Side Channel Marking and Related Conditions on Piloting Performance." U.S. Coast Guard, Washington, D.C., January 1981.

FORM XXX

CALCULATION OF RRF:

TURN REGION

TURN IDENTIFICATION

1. TURN NAME AND LOCATION

2. CHART NO.

3. LATITUDE AND LONGITUDE OF TURN APEX

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)

5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)

6. ENTER MAXIMUM WIND VELOCITY (KNOTS)

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT

8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)

9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)

10. ENTER SHIPS LENGTH (FEET)

11. ENTER SHIPS BEAM (FEET)

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE LESS THAN 1 NM (RADAR) OR DAWN

13. DAYLIGHT CONDITIONS DAY NIGHT DUSK OR DAWN

14. TURN CONFIGURATIONS NONCUTOFF CUTOFF

15. SRA CONFIGURATIONS 3 BUOYS 2 BUOYS 1 BUOY

16. TURN ANGLE 0 TO 20° 20 TO 40° 40 TO 60° 60 TO 90° 90 TO 180° 180 TO 360°

RADIO AID DESIGN PARAMETERS (CIRCLE ONE)

17. GYRO AIDING YES NO

18. RMS NOISE AT SITE 0 TO 6 M 6 TO 18 M 18 TO 36 M

19. DISPLAY FORMAT GRAPHIC W/PREDICTION GRAPHIC W/VECTOR GRAPHIC W/DISTANCE DIGITAL W/TURNING

20. THROUGH SYSTEM RISE TIME 3 SEC 12 SEC 24 SEC

CALCULATE ADJUSTED MN AND SD

21. ENTER BASELINE MN

22. ENTER MN CORRECTION FACTOR

23. ENTER MN CORRECTION FACTOR

24. ENTER MN CORRECTION FACTOR

25. ENTER MN CORRECTION FACTOR

26. ENTER MN CORRECTION FACTOR

27. ENTER MN CORRECTION FACTOR

28. ENTER MN CORRECTION FACTOR

29. ENTER MN CORRECTION FACTOR

30. ENTER MN CORRECTION FACTOR

31. ENTER MN CORRECTION FACTOR

32. ENTER MN CORRECTION FACTOR

33. ENTER MN CORRECTION FACTOR

34. ENTER MN CORRECTION FACTOR

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Figure 6. Sample Calculation for Relative Risk Factor

number of related conditions is it possible to evaluate the original value. The appropriate correction factors for ship size are those that will reproduce the empirical relationship among RRF values that appear in Figure 7. This reproduction will be the objective of the development process.

Several general points about the nature of the AN research can be illustrated by the preceding exercise. First, the RRF is the useful measure for the manual. It works best over a certain range of risk. It has minimum utility under very easy piloting conditions, as in Leg 1 performance in Tables 3, 4, and 5 where all conditions have a risk of 0.0000. The difficult shiphandling tasks of Leg 2 moves conditions out of this end of the range. The RRF also has minimum utility when extremely difficult piloting conditions result in risks of 0.9999. An AN policy of evaluating worst "realistic" cases has minimized this problem. Very conservative correction factors can also result in a large number of high risk values. The correction factors in the draft SRA/RA manual were very conservative. The principal contribution of the additional data in the present experiment will be a decrease in the overall conservatism of the correction factors, allowing for more useful differentiation among conditions.

Second, the high "risk" obtained for the high buoy density/small ship case illustrates the necessity of an examination of the piloted performance in each experimental scenario, as was done in Appendix C, before the data is used in the manual. Such examinations minimize the problem of inappropriate risk.

Third, piloted performance is not easily predicted from ship characteristics. Earlier in the project, during the Ship Variables Experiment,¹⁷ it was hypothesized that measures taken during offline simulation or "sea trials" for the ship models might be used to predict piloted performance or risk. An attempt to find the appropriate measure for three different ships was unsuccessful. The process is described in Appendix H of the present report. If it is possible to find such a measure, or combination of measures, the process will take further and dedicated research. This research is outside the scope of the AN project. The experimental scenarios are run to determine how precisely the pilots can take a given ship through a given channel under given environmental conditions with given aids. The ship's maneuverability, or inherent controllability, is an important component of the process, but only a component. For this AN project, the RRF is measured by "man-in-the-loop" simulation or piloted controllability.

¹⁷W.R. Bertsche, D.A. Atkins, and M.W. Smith. "Aids to Navigation Principal Findings Report on the Ship Variables Experiment: The Effect of Ship Characteristics and Related Variables on Piloting Performance." CG-D-55-81, U.S. Coast Guard, Washington, D.C., November 1981. NTIS-AD-A108771

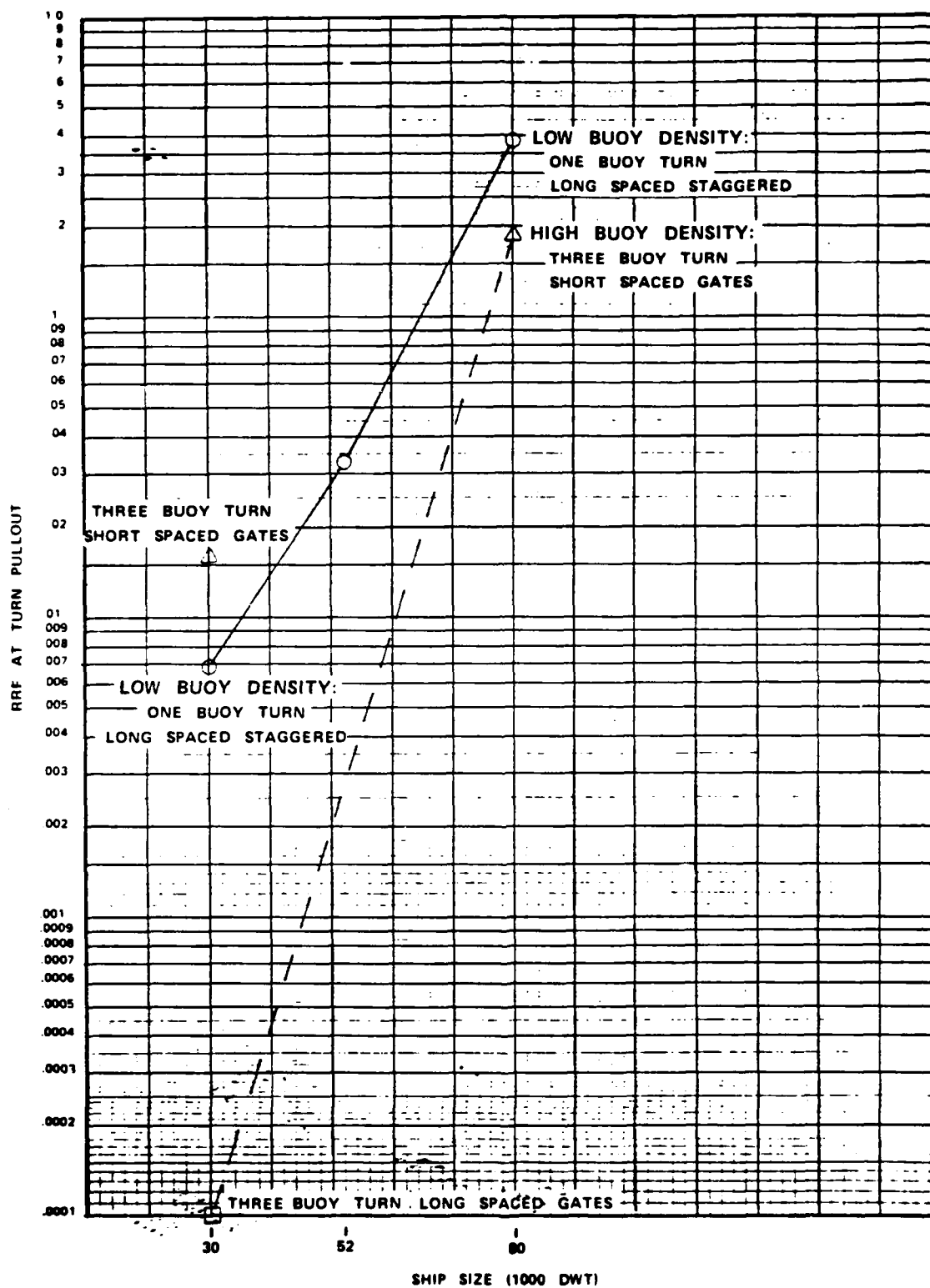


Figure 7. Relative Risk at Turn Pullout for Ship Size

Section 3 SHIP SPEED DATA

3.1 OVERVIEW

The second purpose of the SRA Supplemental Experiment was to determine the effect of ship speed and resulting maneuverability on piloted performance in a restricted waterway. Ship speed data was previously collected in the Ship Variables Experiment. These data showed that ship speed interacts with ship size and together they affect piloted performance.¹⁸ This experiment obtained additional data to further determine the effect of ship speed.

This section compares piloted performance with different size ships (30,000, 52,000, and 80,000 dwt vessels) at two transit speeds (6 knots, slow ahead and 10 knots, half ahead) in two channels. One channel is marked with a low buoy density arrangement (staggered buoys and a one-buoy turn), and the other channel is marked with a high density buoy arrangement (short-spaced gated buoys and a three-buoy turn). A detailed discussion including statistical analyses of performance differences appears in Appendix D. In Appendix D, it was concluded that an increase in ship speed will result in better performance only when "good" information is available to gauge ship position. With high buoy density, the higher speed tracks are smoother compared to the slower speed tracks. At the slower speed the ship is more susceptible to the environmental effects and more difficult to control. With low buoy density, increased speed coupled with larger, more difficult ships degraded performance. See Appendix I for a discussion of the effect of ship speed on maneuverability.

In the draft SRA/RA manual, the variable of ship speed was considered by including a ship speed correction factor when calculating the relative risk factor. The new data will modify the ship speed correction factor used in the SRA/RA manual to calculate the relative risk factor.¹⁹

3.2 SHIP SPEED DATA AND THE SRA/RA MANUAL

The draft SRA/RA manual treated the ship speed variable as a correction factor that is reproduced as Figure 8. There the correction factor was based on a finding that performance for the larger ship deteriorated with increased speed. New scenarios were run with an intermediate-sized ship to evaluate the shape of the function for these ships and at a higher level of buoy density to evaluate the generality of the earlier finding.²⁰ The data now available for the ship speed correction factor are summarized in Tables 6, 7, and 8. A description of the selection of these data and an explanation of the relative risk factor (RRF) appears in Section 2.2 of this report.

¹⁸W.R. Bertsche, D.A. Atkins, and M.W. Smith, op. cit.

¹⁹K.L. Marino and M.W. Smith, op. cit.

²⁰K.L. Marino and M.W. Smith, op. cit.

MEAN AND STANDARD
DEVIATION SHIP SPEED
CORRECTION FACTORS

| SHIP TYPE AND DWT | | | |
|--------------------------------|---------------|--------------------|------------------------------|
| LINE 9: MAXIMUM EXPECTED SPEED | 4 TO 8 KNOTS | TANKER 30,000 DWT | 1.0 |
| | | TANKER 80,000 DWT | 1.0 |
| | | TANKER 120,000 DWT | DATA NOT YET AVAILABLE |
| | | TANKER 250,000 DWT | |
| | | CONTAINER | |
| | | CONTAINER | |
| | | L.N.G. | |
| | 8 TO 12 KNOTS | TANKER 30,000 DWT | 1.0 |
| | | TANKER 80,000 DWT | 1.0 |
| | | TANKER 120,000 DWT | DATA NOT YET AVAILABLE |
| | | CONTAINER | |
| | | CONTAINER | |
| | | L.N.G. | |

NOTE: The following turns are not defined in the present text:
DWT deadweight ton
LNG liquified natural gas (carrier)

Figure 8. Adapted from a Figure in the 1982 Draft Manual:
Ship Speed Correction Factors for Turn Regions

TABLE 6. SHIP SPEED AND TURN (PULLOUT) PERFORMANCE

| Ship Size (dwt) | 6 Knots | | | | | 10 Knots | | | | |
|--------------------|----------|--------------|-------------------|------------------------------------|----------------------------|--------------------------------------|--------------|------|-----------------------|----------------------------|
| | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor | Scenario | Data Line | Mean | Standard Deviation | Relative Risk Factor |
| 30,000 | SV 2 | 3 | 72R | 45 | 0.0068 | Low Buoy Density (One Turn Buoy) | | | | |
| | | | | | | SV 3 | 3 | 90R | 43 | 0.0082 |
| | | | | | | | | | | |
| 52,000 | SRA 11 | 3 | 71R | 54 | 0.0336 | SRA 12 | 3 | 83R | 49 | 0.0233 |
| | | | | | | | | | | |
| 80,000 | SV 6 | 3 | 137R | 65 | 0.3859 | SV 8 | 4 | 151R | 98 | 0.4253 |
| | | | | | | | | | | |
| 80,000 | SV 7 | 3 | 108R | 54 | 0.1841 | High Buoy Density (Three Turn Buoys) | | | | |
| | | | | | | SRA 5 | 3 | 74R | 46 | 0.0202 |
| | | | | | | | | | | |

¹Means are shown as feet to right or left of centerline

²Standard deviations are in feet.

TABLE 7. SHIP SPEED AND RECOVERY PERFORMANCE

| Ship Size (dwt) | 6 KNOTS | | | | | 10 KNOTS | | | | |
|--------------------|--------------------------------------------------|--------------|-------------------|------------------------------------|----------------------------|-------------------|--------------|-------------------|------------------------------------|----------------------------|
| | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor |
| | | | | | | | | | | |
| | FOLLOWING CURRENT/WIND (LEG 1) | | | | | | | | | |
| | <u>Low Buoy Density (Long-Spaced, Staggered)</u> | | | | | | | | | |
| 30,000 | SV 2 ³ | 22 | 3R | 73 | 0.0044 | SV 3 ³ | 21 | 27R | 61 | 0.0016 |
| 52,000 | SRA 11 | 12 | 45R | 20 | 0.0000 | SRA 12 | 11 | 19R | 38 | 0.0000 |
| 80,000 | SV 6 ³ | 20 | 35R | 111 | 0.1081 | SV 8 ³ | 20 | 63R | 107 | 0.1326 |
| | <u>High Buoy Density (Short-Spaced, Gated)</u> | | | | | | | | | |
| 80,000 | SV 7 ³ | 22 | 18L | 109 | 0.0900 | SRA 5 | 11 | 33R | 20 | 0.0000 |
| | CROSSCURRENT/WIND (LEG 2) | | | | | | | | | |
| | <u>Low Buoy Density (Long-Spaced, Staggered)</u> | | | | | | | | | |
| 30,000 | SV 2 | 6 | 88R | 60 | 0.0367 | SV 3 | 8 | 115R | 53 | 0.0526 |
| 52,000 | SRA 11 | 12 | 64R | 85 | 0.0827 | SRA 12 | 10 | 73R | 51 | 0.0116 |
| 80,000 | SV 6 | 6 | 88R | 63 | 0.0918 | SV 8 | 6 | 142R | 80 | 0.3264 |
| | <u>High Buoy Density (Short-Spaced, Gated)</u> | | | | | | | | | |
| 80,000 | SV 7 | 13 | 25L | 108 | 0.1213 | SRA 5 | 12 | 46R | 53 | 0.0064 |

¹Means are shown as feet to right or left of channel centerline.²Standard deviations are in feet.³SV Leg 1 performance is not directly comparable to Leg 1 performance in other experiments.

TABLE 8. SHIP SPEED AND TRACKKEEPING PERFORMANCE

| Ship Size (dwt) | 6 KNOTS | | | | | 10 KNOTS | | | | |
|--------------------|-------------------------------------------|--------------|-------------------|------------------------------------|----------------------------|-------------------|--------------|-------------------|------------------------------------|----------------------------|
| | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor |
| | FOLLOWING CURRENT/WIND LEG 1) | | | | | | | | | |
| | Low Buoy Density (Long-Spaced, Staggered) | | | | | | | | | |
| 30,000 | SV 2 ³ | 15 | 2L | 37 | 0.0000 | SV 3 ³ | 15 | 6R | 33 | 0.0000 |
| 52,000 | SRA 11 | 8 | 19R | 29 | 0.0000 | SRA 12 | 9 | 7L | 32 | 0.0000 |
| 80,000 | SV 6 ³ | 15 | 2L | 90 | 0.0371 | SV 8 ³ | 14 | 14L | 39 | 0.0000 |
| | High Buoy Density (Short-Spaced, Gated) | | | | | | | | | |
| 80,000 | SV 7 ³ | 15 | 14L | 43 | 0.0000 | SRA 5 | 9 | 15R | 22 | 0.0000 |
| | CROSSCURRENT/WIND (LEG 2) | | | | | | | | | |
| | Low Buoy Density (Long-Spaced, Staggered) | | | | | | | | | |
| 30,000 | SV 2 | 20 | 39R | 73 | 0.0165 | SV 3 | 22 | 72R | 49 | 0.0044 |
| 52,000 | SRA 11 | 19 | 31R | 38 | 0.0000 | SRA 12 | 22 | 46R | 37 | 0.0010 |
| 80,000 | SV 6 | 18 | 44L | 50 | 0.0054 | SV 8 | 21 | 31R | 38 | 0.033C |
| | High Buoy Density (Short-Spaced, Gated) | | | | | | | | | |
| 80,000 | SV 7 | 19 | 17L | 69 | 0.0157 | SRA 5 | 18 | 40R | 34 | 0.0000 |

¹Means are shown as feet to right or left of channel centerline.²Standard deviations are in feet.³SV Leg 1 performance is not directly comparable to Leg 1 performance in other experiments.

Performance data for the critical turn maneuver in Table 6 can be used to represent the ship speed findings. Data for the other maneuvers support the same general conclusions. The RRF values from Table 6 are plotted in Figure 9. The 6-knot values have already appeared in Figure 7 in Section 2.2 as a ship size function. There, it was concluded that the RRF function was more meaningful than the plots of the means or the standard deviation in representing the effect of ship size. Since the RRF measure considers the two simpler measures and the ship and channel dimensions, it is less sensitive to specific scenario events. The appropriate correction factors for the mean and standard deviation are assumed to be those which will reproduce the generally logarithmic function of risk over ship size. The data for the 10-knot scenarios is superimposed as a second ship-size function.

The pattern of relative risk illustrated in Figure 9 identifies the correction factors needed (or not needed) to describe the observed performance. The ship size effect is much larger than the ship speed effect. The needed ship size correction factors were discussed in Section 2.2. The effect of ship speed on risk with low buoy density is small and inconsistent. The risk increases with speed for the 30,000 and 80,000 dwt ship and decreases for the 52,000 dwt ship. Inspection of Tables 7 and 8 shows that this inversion is not consistent across the other maneuvers. For the 80,000 dwt ship there is data available at a high buoy density. There is a large effect of ship speed and it is consistent across maneuvers. However, this improvement in risk with increased speed depends on a buoy density higher than any likely to occur at sea: three buoys markings the turn and short-spaced gated buoys. This condition seems to explain the effect of ship speed on risk but does not have any generality for application. These data suggest that a ship speed correction factor is not necessary or appropriate. The quantitative content of the revised SRA/RA manual should be based primarily on the larger body of available data for the 6-knot speed.

The revised SRA/RA manual should contain some discussion of speed and, possibly, some quantitative data to guide the user in atypical situations or in operational decisions. Of the factors considered here -- speed, ship size/maneuverability, and buoy density -- the critical combination is a large ship, a high speed, and low buoy density. Of these factors, speed, within the range the pilot considers a "safe speed for the prevailing circumstances and conditions," has the smallest effect. Larger, and more reliable, improvements in performance risk can be expected from closing a waterway to larger ships or from increasing buoy density, especially in the turns.

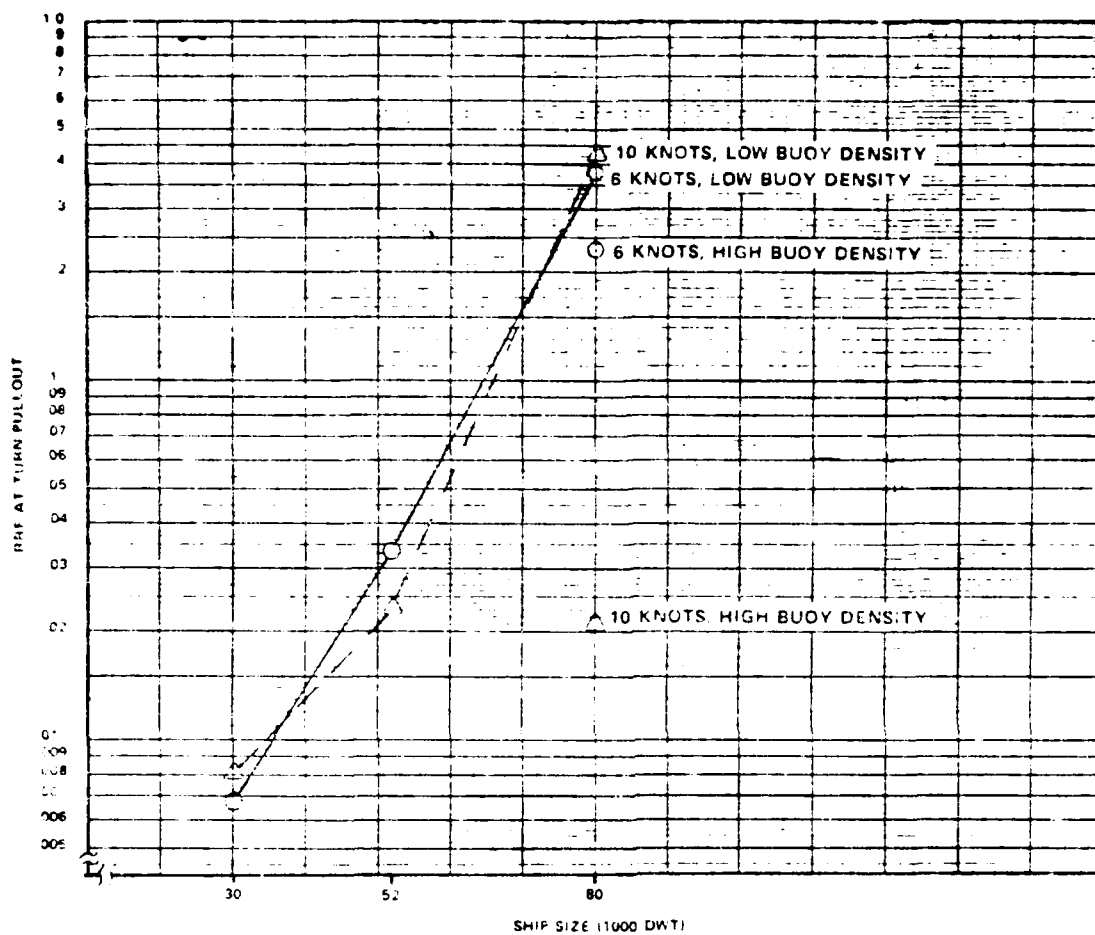


Figure 9. Relative Risk at Turn Pullout for Ship Speed

Section 4

CHANNEL WIDTH DATA

4.1 OVERVIEW

The third purpose of the SRA Supplemental Experiment was to evaluate the effect of channel width and ship size on piloted performance. Channel width data, primarily collected in the Channel Width²¹ Experiment, indicated that as channel width increases from 500 to 800 feet, there is a proportional increase in the width of the band of transits. Channel width is a quantitative and continuous variable which was found to impact piloted performance.

This section evaluates piloted performance with two ships (30,000 and 80,000 dwt vessels) in two different channels (500 and 800 feet wide). The 500-foot channel is marked by gates spaced at either 5/8 nm or 1-1/4 nm intervals, and the 800-foot channel is marked by gates spaced at 1-1/4 nm intervals. A detailed discussion including statistical analyses of performance differences appears in Appendix E. In Appendix E, it was concluded that in the 500-foot channel as ship size increases performance becomes poorer. Piloted performance with the 80,000 dwt ship is more "risky" in the 500-foot channel than the 800-foot channel because the large ship needs the wide channel. Piloted performance was best with the 30,000 dwt ship in the 500-foot channel, and piloted precision worsened as channel width increased. Possibly, the small bow in the wide channel does not provide an adequate reference for judging the ship's position. Possibly the pilots are less cautious with a small ship in a wide channel.

A channel width correction factor was included in the relative risk factor calculation that was developed in the draft SRA/RA manual. The new data obtained by this experiment will be used to modify the channel width correction factor used in the revised SRA/RA manual.

4.2 CHANNEL WIDTH DATA AND THE SRA/RA MANUAL

The draft SRA/RA manual treated the channel width variable as a correction factor which was linearly interpolated as illustrated in Figure 10. It was based on performance with the 30,000 dwt ship in a 500 and an 800-foot channel. The relationship observed with that ship was to be applied for all size ships as channel width increased. Performance for the 80,000 dwt ship in the 500-foot channel was already available in the earlier Ship Variables Experiment. The present experiment evaluated performance for the 80,000 dwt ship in the 800-foot channel; Scenario 6 provides the missing cell.

²¹M. W. Smith and W. R. Bertsche. "Aids to Navigation Principal Findings Report on the Channel Width Experiment: The Effects of Channel Width and Related Variables on Piloting Performance." U.S. Coast Guard, Washington, D.C., January 1981.



CHANNEL WIDTH: W

$W < 500 \text{ FEET}^*$

$$MCWID = SCWID = 1.0$$

$500 < W < 800 \text{ FEET}$

$$MCWID = SCWID = 1 + [(1.5)(W-500)/(300)]$$

*THE FACTOR 1.0 IS SELECTED AS CONSERVATIVE

Note: The following turns are not defined in the present text
 MCWID correction factor to be applied to mean to correct for channel width
 SCWID correction factor to be applied to standard deviation for correct for channel width

Figure 10. Adaptation of figure from 1982 Draft Manual:
 Channel Width Correction Factors for Turn Regions

Table 9 identifies data available to evaluate the interaction between ship size and channel width. The numbers on the table in parentheses identify buoy spacing. Most of the data available pertains to the 30,000 dwt ship in the 500-foot channel. Scenario 6 from this experiment consists of the 80,000 dwt ship transiting in an 800-foot channel and was included to allow further analysis of the channel width and ship size interaction.

TABLE 9. CHANNEL WIDTH CONDITIONS

| Ship Size (dwt) | Channel Width | |
|-----------------|---------------|---------------|
| | 500 feet | 800 feet |
| 30,000 | CW 2 | CW 6 (1-1/4) |
| | SV 5 (5/8) | |
| | OS 1 | |
| | CW 4 (1-1/4) | |
| 80,000 | SV 7 (5/8) | SRA 6 (1-1/4) |

All the data now available for the development of the channel width correction factors (for the mean and standard deviation and for the several ship maneuvers) are summarized in Tables 10, 11, and 12.

The observed channel width effect for the 80,000 dwt ship is not the same as would have been predicted from the data available on the 30,000 dwt ship. Performance for the three conditions evaluated earlier and the prediction they make for the fourth are summarized in Table 13. The values are for the critical turn maneuver. The same general points can be made with data for the other maneuvers. Here, the 30,000 dwt ship and 500-foot channel value is a pool of the two long buoy spacing scenarios. The high buoy density scenarios were discarded because they over-estimated risk (and

TABLE 10. CHANNEL WIDTH AND TURN (PULLOUT) PERFORMANCE

| Ship Size (dwt) | Buoy ³ Spacing (nm) | 500-Foot Channel | | | | | 800-Foot Channel | | | | |
|--------------------|--------------------------------------|------------------|--------------|-------------------|------------------------------------|----------------------------|------------------|--------------|-------------------|------------------------------------|----------------------------|
| | | Scenario | Data Line | Mean ¹ | Standard ² Deviation | Relative Risk Factor | Scenario | Data Line | Mean ¹ | Standard ² Deviation | Relative Risk Factor |
| 30,000 | 5/8 | CW 2 | 3 | 59R | 47 | 0.0041 | | | | | |
| | 5/8 | SV 5 | 3 | 57R | 59 | 0.0162 | | | | | |
| | 1-1/4 | OS 1 | 3 | 59R | 34 | 0.0001 | | | | | |
| | 1-1/4 | CW 4 | 3 | 72R | 32 | 0.0003 | CW 6 | 3 | 28R | 94 | 0.0007 |
| 80,000 | 5/8 | SV 7 | 3 | 107R | 54 | 0.1841 | SRA 6 | 3 | 34L | 95 | 0.0023 |

¹Means are shown as feet to right or left of centerline.

²Standard deviations are in feet.

³All turns are marked by three buoys.

TABLE 11. CHANNEL WIDTH AND RECOVERY PERFORMANCE

| Ship Size (dwt) | Buoy Spacing ³ (nm) | 500-Foot Channel | | | | | 800-Foot Channel | | | | |
|--------------------|--------------------------------------|------------------|-----------------|-------------------|------------------------------------|----------------------------|------------------|--------------|-------------------|------------------------------------|----------------------------|
| | | Scenario | Data Line | Mean ¹ | Standard ² Deviation | Relative Risk Factor | Scenario | Data Line | Mean ¹ | Standard ² Deviation | Relative Risk Factor |
| 30,000 | 5/8 | CW 2 | 17 | 6L | 40 | 0.0000 | | | | | |
| | 5/8 | SV 5 | 22 ³ | 46L | 89 | 0.0366 | | | | | |
| | 1-1/4 | OS 1 | 11 | 20R | 26 | 0.0000 | | | | | |
| | 1-1/4 | CW 4 | 22 | 7R | 39 | 0.0000 | CW 6 | 20 | 18R | 60 | 0.0000 |
| | 5/8 | SV 7 | 22 ³ | 18L | 109 | 0.0907 | SRA 6 | 8 | 45R | 31 | 0.0000 |
| 30,000 | 5/8 | CW 2 | 11 | 64R | 66 | 0.0233 | | | | | |
| | 5/8 | SV 5 | 10 | 62R | 72 | 0.0316 | | | | | |
| | 1-1/4 | OS 1 | 8 | 104R | 36 | 0.0055 | | | | | |
| | 1-1/4 | CW 4 | 7 | 90R | 32 | 0.0005 | CW 6 | 11 | 96R | 70 | 0.0002 |
| | 5/8 | SV 7 | 10 | 11L | 100 | 0.0892 | SRA 6 | 6 | 18L | 75 | 0.0000 |

¹Means are shown, as feet to right or left of centerline.²Standard deviations are in feet.³SV Leg 1 Recovery is not comparable to Leg 1 in other experiments.

TABLE 12. CHANNEL WIDTH AND TRACKKEEPING PERFORMANCE

| Ship Size (dwt) | Buoy Spacing ³ (nm) | 500-Foot Channel | | | | | 800-Foot Channel ¹ | | | | |
|--------------------------------|--------------------------------------|------------------|--------------|-------------------|-------------------------|----------------------------|-------------------------------|--------------|-------------------|------------------------|----------------------------|
| | | Scenario | Data Line | Mean ¹ | Standard 2 Deviation | Relative Risk Factor | Scenario | Data Line | Mean ¹ | Standard2 Deviation | Relative Risk Factor |
| Following Current/Wind (Leg 1) | | | | | | | | | | | |
| 30,000 | 5/8 | CW 2 | 12 | 3L | 31 | 0.0000 | | | | | |
| | 5/8 | SV 5 | 15 | 16L | 26 | 0.0000 | | | | | |
| | 1-1/4 | OS 1 | 9 | 13R | 24 | 0.0000 | | | | | |
| | 1-1/4 | CW 4 | 16 | 2L | 35 | 0.0000 | CW 6 | 16 | 1R | 61 | 0.0000 |
| | 5/8 | SV 7 | 15 | 14L | 43 | 0.0000 | SRA 6 | 8 | 45R | 31 | 0.0000 |
| Crosscurrent/Wind (Leg 2) | | | | | | | | | | | |
| 30,000 | 5/8 | CW 2 | 21 | 31R | 46 | 0.0002 | | | | | |
| | 5/8 | SV 5 | 25 | 29R | 30 | 0.0000 | | | | | |
| | 1-1/4 | OS 1 | 18 | 86R | 44 | 0.0064 | | | | | |
| | 1-1/4 | CW 4 | 24 | 53R | 66 | 0.0155 | CW 6 | 24 | 75R | 85 | 0.0007 |
| | 5/8 | SV 7 | 19 | 17L | 69 | 0.0157 | SRA 6 | 17 | 22R | 63 | 0.0000 |
| 80,000 | 5/8 | | | | | | | | | | |

¹Means are shown as feet to right or left of centerline.

²Standard deviations are in feet.

Appendix C). The two scenarios with three-buoy turns and long spacing were pooled on the assumption that they are two available estimates of the same condition. The single available estimates for the 80,000 dwt ship in 500-foot channel and for the 30,000 dwt ship in the 800-foot channel are carried over from Table 10. For the 80,000 dwt ship in the 800-foot channel, the mean and standard deviations were derived by assuming that their change with channel width would be the same as the change for the 30,000 dwt ship. The RRF was calculated using the derived values. The value of 0.0205 is considerably larger than the observed value of 0.0023 that appears in Table 10.

The reason for the discrepancy between the derived and observed performance is in the interaction between ship size and channel width. The change in performance with channel width is not the same for the two ships. For the 30,000 dwt ship the precision of performance as indexed by the standard deviation deteriorates considerably in the wider channel. Two possible reasons for this deterioration were suggested in Appendix E. The pilots may change their standard of caution, knowing the small ship is safe in the wide channel; the small bow in the wide channel may not provide a sufficient visual reference to allow the pilots to judge their position in the channel. For the 80,000 dwt ship the same deterioration in precision with channel width does not occur. For this reason risk decreases more with increased channel width for the larger ship. A correction factor based on the performance of the smaller ship alone is too conservative to apply to the larger ship. Performance with both ships will have to be considered in the development of the channel width correction factor(s).

A graphic presentation of the risk values for the conditions discussed appears in Figure 11. Notice that the biggest effect is still that of ship size: the 80,000 dwt ship is at greater risk than is the 30,000 dwt ship at either channel width. Channel width moderates the risk: there is a considerable decrease for the larger ship in the wider channel and the risk for the 30,000 dwt ship is relatively low for either channel width. The higher "risk" for the 30,000 dwt ship in the 800-foot channel is the result of the larger standard deviation. The resulting inversion in risk values con-

TABLE 13. PREDICTION OF RISK FOR THE 80,000 DWT SHIP
IN AN 800-FOOT CHANNEL

| | Channel Width | | | | | |
|-----------------|---------------|--------------------|----------------------|----------|--------------------|----------------------|
| | 500-Feet | | | 800-Feet | | |
| Ship Size (dwt) | Mean | Standard Deviation | Relative Risk Factor | Mean | Standard Deviation | Relative Risk Factor |
| 30,000 | 65R | 33 | 0.0002 | 28R | 94 | 0.0007 |
| 80,000 | 107R | 54 | 0.1841 | 70R | 115 | 0.0205 |

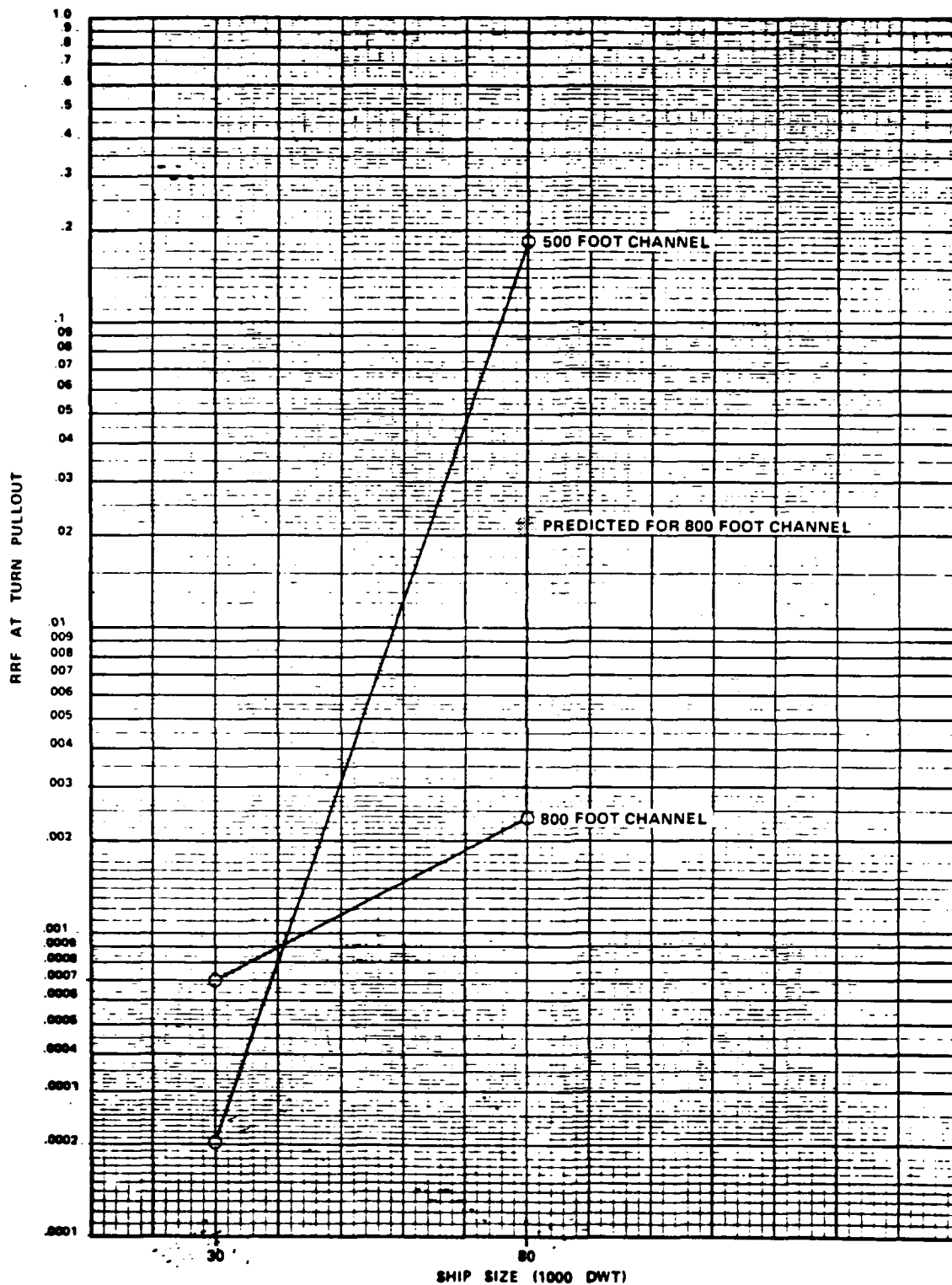


Figure 11. Risk in the Turn Pullout for Ship Size and Channel Width

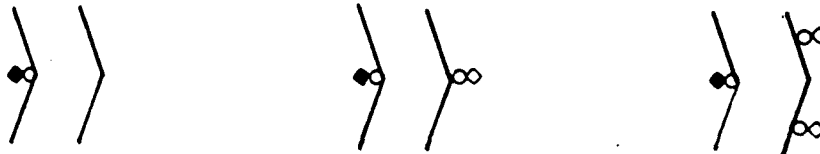
tributes little to the evaluation process and should not appear in the final manual. It should be eliminated either by the selection of the channel width correction factor or, possibly, by blanking out the higher relative risk values for the smaller ship.

Section 5

TURN MANEUVER DATA

5.1 OVERVIEW

The fourth purpose of this experiment was to provide additional data on the performance of aid number and arrangement for the critical turn maneuver. Over several experiments the 35-degree noncutoff turn has been marked with one, two, and three buoys arranged as diagrammed.



Previously it was determined that the turn is the most critical portion of the channel, therefore, the 35-degree turn maneuver has always been included in scenarios run on the USCG/SA simulator since it is the most difficult, yet believable maneuver. By maneuvering for the 35-degree noncutoff turn, differences in variables of interest such as ship size, day/night, and buoy arrangement are identified.

The Turn Lighting Experiment²² identified that the variables of ship size, buoy arrangement, and ambient lighting are critical to piloting performance in turns. Table 14 identifies the scenarios that are available to evaluate these variables. The shaded portion of the table shows the scenarios which were run in this experiment. This table summarizes piloted performance in the turn under a variety of conditions. It has been revised in accordance with new data and includes key statistics such as the mean, standard deviation, and RRF for each scenario.

In this section and Appendix F, the new data collected in this experiment was evaluated by comparing them to previously collected data. In Appendix F, it was concluded that a one-buoy turn is only acceptable for nighttime transits with a 30,000 dwt ship or smaller. For ships 80,000 dwt or larger, a three-buoy turn is recommended for nighttime transits. During the day two and three buoy turns produce acceptable tracks for all three ships. The one-buoy turn results in acceptable performance for the 30,000 and 52,000 dwt ships.

5.2 TURN MANEUVER DATA AND THE DESIGN MANUAL

The draft SRA/RA manual treated turnmarking as a discrete event represented by means and standard deviations observed on the simulator. While buoy number is a continuous, quantitative variable for the cost of the aids; this does not seem to be the case for performance. The arrangement of the buoys seems to be an important factor in the pilots' use of them. They make a unique maneuver through the turn for each number/arrangement of

²²J. Multer and M. W. Smith, op. cit.

buoys. For this reason it is more appropriate to use performance values observed for each possibility than it is to treat buoy number as a continuous variable and interpolate (or extrapolate) missing conditions. The data available for the 35-degree noncutoff turn are summarized in Table 14. Two other variables, ship size and day/night, found to have major effects on the turn maneuver have also been included in the table. The conventions for selecting the data and for calculating the relative risk factor have been discussed in Section 2.2.

The data in Table 14 are arranged to facilitate the evaluation of performance as a function of buoy number. For the 30,000 dwt ship in the daytime, the expected improvement with buoy number appears. The greater change is between three and two buoys. The setup and pullout buoys in the three-buoy arrangement provide a considerable decrease in risk over the single outside buoy in the two-buoy arrangement. However, for the smaller ship in the daytime even the two-buoy turn provides for a risk that is among the smallest in the table. (Note that these data come from one-way traffic scenarios. The relative performance of these arrangements might be different in the two-way traffic situation.) Overall, the small ship in the daytime allows the greatest options in turn marking. For the 80,000 dwt ship, risk is greater for all conditions. There is also an unexpected inversion in the daytime conditions for the larger ship. Comparisons in performance among this many scenarios at one time reveals relationships that are not obvious when scenarios are compared in pairs or smaller groups. It is apparent from this table that the risk for the 80,000 dwt ship during the day with three buoys is overestimated. Possible reasons for this overestimation are discussed in Appendix F. The risk should not be greater than the risk with two buoys. In the manual this overestimation should be indicated in some way. Possibly by stating the risk as <0.1841 or even <0.0485 . Every measurement is influenced by the experimental conditions under which it was collected. Successive comparisons provide a check on these influences.

Nighttime performance was evaluated separately and is also summarized in Table 14. Performance for the 30,000 dwt ship shows the nighttime strategy described in Appendix F. The mean in the pullout is on the centerline and the standard deviation is relatively large. Because the ship is making a harder turn at night, the actual risk is not as low as the value calculated using the observed mean and standard deviation. The manual user should be told that risk for nighttime turns is underestimated relative to risk in daytime turns.

The data in Table 14, including ship size and day/night as variables, can be used to make operational decisions. Given the channel dimensions, the environmental conditions and the turn as marked, what is the risk for a size of ship? Is there a meaningful difference between day and night for a given ship size? What tradeoffs are possible between operational and marking decisions? As an example, assume that a channel with a two-buoy turn has a history of reasonable safety for 30,000 dwt ships transiting both in the daytime and at night. The nighttime risk of 0.0110 becomes a standard or objective. This procedure of selecting the risk for an experienced set of conditions as acceptable was discussed and illustrated in the draft SRA/RA manual in Section 3. What is the risk of bringing in an 80,000 dwt ship?

TABLE 14. PULLOUT PERFORMANCE FOR TURNMARKING, SHIP SIZE, AND DAY/NIGHT

| | Day | | | | | | Night | | | | | |
|-----------------|------------------|----------|-----------|------|--------------------|----------------------|------------------|----------|-----------|------|--------------------|----------------------|
| | Experiment | Scenario | Data Line | Mean | Standard Deviation | Relative Risk Factor | Experiment | Scenario | Data Line | Mean | Standard Deviation | Relative Risk Factor |
| 10,000 dwt ship | One-Side | 1 | 3 | 59R | 34 | 0.0001 | Turn Light | 1 | 2 | 8R | 56 | 0.0012 |
| | One-Side | 6 | 3 | 94R | 33 | 0.0035 | Turn Light | 8,9 | 3 | 28R | 67 | 0.0110 |
| | Ship Variables | 2 | 3 | 72R | 45 | 0.0068 | SRA Supplemental | 9 | 3 | 6R | 73 | 0.0126 |
| | | | | | | | | | | | | |
| 80,000 dwt ship | Ship Variables | 7 | 3 | 107R | 54 | 0.1841 | SRA Supplemental | 8 | 3 | 79R | 70 | 0.1383 |
| | SRA Supplemental | 7 | 3 | 81R | 45 | 0.0485 | Turn Light | 10 | 3 | 187R | 58 | 0.7019 |
| | Ship Variables | 6 | 3 | 137R | 65 | 0.3859 | | | | | | |
| | | | | | | | | | | | | |

The nighttime risk of 0.7019 seems to be an excessive increase; the nighttime transit of the larger ships does not seem to be an acceptable alternative. Even daytime transits have a risk of 0.0485 which does not meet the objective. Increasing the marking for the 80,000 dwt ship might be an alternative. Even with three buoys, the nighttime risk is 0.1383 and does not meet the objective. Three buoys in the daytime is the only remaining possibility. If the value of 0.1841 in the table is accepted as accurate, it does not meet the standard. The conservative decision would be not to allow the transits.

There is an inconsistency in Table 14 in the risk values for transits with the 80,000 dwt ship. The risk value for daytime transits with three buoys should not be higher than that for the two-buoy turn or for nighttime transits. Such inconsistencies do not contribute to the decision process. In the selection of data for the final manual, great care must be taken when selecting data from a number of different experiments.

While it does not seem appropriate to interpolate on buoy number, the interpolation on ship size as a variable is central to the applicability of project findings. For maximum utility, it should be possible to correct these data for ship size. These data should both be used in the development of the general ship size correction factors and benefit from the process.

Section 6

EFFECT OF DESIGN CONDITIONS

6.1 OVERVIEW

Early in the AN project it was hypothesized that differences in the performance of aid arrangements would not be revealed by easy shiphandling tasks. The basic experimental scenario was designed with a variety of tasks that differed in the degree to which they forced the pilot to depend on the buoys (or other aid systems) for timely information as to his ship's position and status. That scenario had the ship transiting at 6 knots with a 1-foot underkeel clearance. The pilot was asked to first maneuver and trackkeep with a following current and wind, make a turn and pull out, and then maneuver to the centerline and trackkeep with a crosstrack current and wind. The hypothesis was supported by piloted performance in the first experiment.²³ Performance in Leg 1 with a following current and wind was quite precise and relatively insensitive to differences among experimental conditions. Performance in Leg 2, following the turn, with crosstrack current and wind, was much less precise and more sensitive to differences. Therefore, differences in performance for different aid or environmental conditions were better measured with difficult shiphandling tasks. The same basic assumptions and basic scenario has been maintained through all the experiments. The basic scenario is described in this report in Section 1.2.4; the performance differences obtained in this way are documented in all the subsequent sections of this report.

The simulated scenario effects are not representative of conditions that would be expected with any high frequency at sea. Pilots would choose a faster speed of 10 to 14 knots under the environmental conditions for the greater maneuverability they expect it to give the ship (see Appendix I). Also crosscurrent and crosswind of the velocities simulated, while not extreme, exist with a relatively low frequency. The imposition of these conditions not only allows a sensitivity to differences in aid arrangements, but has the second effect of building a degree of conservatism into the data and the manual.

A purpose of this experiment is to evaluate the degree of conservatism of the "basic" scenario by comparing the design condition to conditions more representative of those that would be expected to occur with higher frequency in the real world. This evaluation of the difference between design and representative conditions is conceptually related to validation, an evaluation of the difference between simulator and at-sea data.²⁴ This

²³M.W. Smith and W.R. Bertsche. "Aids to Navigation Principal Findings on the CAORF Experiment. The Performance of Visual Aids to Navigation as Evaluated by Simulation." Interim Report, U.S. Coast Guard, February 1981.

²⁴M.W. Smith, K.L. Marino, J. Muller, and J.D. Moynihan. "Aids to Navigation Draft Principal Findings Report: Validation for a Simulator-Based Design Project." U.S. Coast Guard, Washington, D.C., March 1984.

section will first compare performance for the difficult shiphandling requirements imposed by the design conditions with a more representative set of shiphandling requirements to evaluate the degree of conservatism. The newly available data for representative conditions can also be compared to a Radar I²⁵ scenario run to list design conditions under the very limited visibility in that experiment.

6.2 THE DESIGN CONDITION EVALUATION AND THE SRA/RA MANUAL

The degree of conservatism that the design conditions introduce into the data and risk assessments planned for the manual can be evaluated for at least one set of conditions, using the new SRA 10 data. Performance and risk in the SRA 10 Experiment is summarized in Tables 15, 16, and 17, along with several scenarios from earlier experiments (scenarios that have been described earlier in this report). All the earlier scenarios included were run with the design conditions of 6-knot speed, 1-foot underkeel clearance. There are no meaningful performance differences among the scenarios in Leg 1. There are differences between the design and representative conditions in the turn pullout, recovery, and trackkeeping portions of Leg 2. Performance is worse with design conditions. As an example, in the pullout both the means and standard deviations are twice as large for the more difficult shiphandling conditions. The risks calculated are higher than would have been obtained if more representative conditions had been simulated.

There is no plan to make a quantitative adjustment to any measures presented in the manual. However, there should be some discussion helping the user to interpret risk measures in terms of their representativeness, or match to a probability to be expected at sea, and in terms of conservatism, or a safety margin for low-frequency environmental or shiphandling condition.

²⁵M. Multer and M.W. Smith, op. cit.

TABLE 15. DESIGN CONDITIONS AND TURN (PULLOUT) PERFORMANCE

| Buoy Spacing ³ (nm) | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor |
|--------------------------------|----------------------------------------|-----------|-------------------|---------------------------------|----------------------|
| 1-1/4 | <u>No Current or Wind/10 Knots</u> | | | | |
| | SRA 10 | 3 | 25R | 21 | 0.0000 |
| 5/8 | <u>Design Current and Wind/6 Knots</u> | | | | |
| | CW 2 | 3 | 59R | 47 | 0.0041 |
| | SV 5 | 3 | 57R | 59 | 0.0162 |
| | OS 1 | 3 | 59R | 34 | 0.0001 |
| 1-1/4 | CW 4 | 3 | 72R | 32 | 0.0003 |

¹Means are shown as feet to right or left of centerline.

²Standard deviations are in feet.

³All turns are marked by three buoys.

TABLE 16. DESIGN CONDITIONS AND RECOVERY PERFORMANCE

| Buoy Spacing ³ (nm) | Scenario | Leg 1 | | | Leg 2 | | | | |
|----------------------------------------|----------|------------------------------------|-------------------|------------------------------------|-------------------------|----------------------------|------|-----------------------|-------------------------|
| | | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor | Data Line | Mean | Standard Deviation | Relative Risk Factor |
| | | <u>No Current or Wind/10 Knots</u> | | | | | | | |
| 1-1/4 | SRA 10 | 13 | 52R | 19 | 0.0000 | 5 | 33R | 18 | 0.0000 |
| <u>Design Current and Wind/6 Knots</u> | | | | | | | | | |
| | | <u>(Following Current/Wind)</u> | | | | <u>(Crosscurrent/Wind)</u> | | | |
| 5/8 | CW 2 | 17 | 6L | 40 | 0.0000 | 11 | 64R | 66 | 0.0233 |
| 5/8 | SV 5 | 22 | 46L | 89 | 0.0366 ⁴ | 10 | 62R | 72 | 0.0316 |
| 1-1/4 | OS 1 | 11 | 20R | 26 | 0.0000 | 8 | 104R | 36 | 0.0055 |
| 1-1/4 | CW 4 | 22 | 7R | 39 | 0.0000 | 7 | 90R | 32 | 0.0005 |

¹Means are shown as feet to right or left of channel centerline.

²Standard deviations are in feet.

³All turns are marked by three buoys.

⁴The Ship Variables scenarios began with a maneuver into the channel.

TABLE 17. DESIGN CONDITIONS AND TRACKKEEPING PERFORMANCE

| | | Leg 1 | | | Leg 2 | | | | |
|--------------------------------------|----------|----------------------------------------|-------------------|------------------------------------|-------------------------|----------------------------|------|-----------------------|-------------------------|
| Buoy Spacing ³ (nm) | Scenario | Data Line | Mean ¹ | Standard Deviation ² | Relative Risk Factor | Data Line | Mean | Standard Deviation | Relative Risk Factor |
| | | No Current or Wind/10 Knots | | | | | | | |
| 1-1/4 | SRA 10 | 9 | 14R | 25 | 0.0000 | 12 | 10R | 16 | 0.0000 |
| | | <u>Design Current and Wind/6 Knots</u> | | | | | | | |
| | | <u>(Following Current/Wind)</u> | | | | <u>(Crosscurrent/Wind)</u> | | | |
| 5/8 | CW 2 | 12 | 3L | 31 | 0.0000 | 21 | 31R | 46 | 0.0002 |
| 5/8 | SV 5 | 13 | 7L | 17 | 0.0000 | 25 | 29R | 30 | 0.0000 |
| 1-1/4 | OS 1 | 9 | 13R | 24 | 0.0000 | 18 | 86R | 44 | 0.0064 |
| 1-1/4 | CW 4 | 16 | 2L | 35 | 0.0000 | 24 | 53R | 66 | 0.0155 |

¹Means are shown as feet to right or left of channel centerline.²Standard deviations are in feet.³All turns are marked by three buoys.

APPENDICES

- A CHARACTERISTICS OF THE USCG/SA SIMULATOR
- B SRA SUPPLEMENTAL EXPERIMENT: INSTRUCTIONS TO THE PILOT
- C PILOTED PERFORMANCE AS A FUNCTION OF SHIP SIZE
- D PILOTED PERFORMANCE AS A FUNCTION OF SHIP SPEED
- E PILOTED PERFORMANCE AS A FUNCTION OF CHANNEL WIDTH
- F PILOTED PERFORMANCE AS A FUNCTION OF TURNMARKING
- G EFFECT OF DESIGN CONDITIONS ON PILOTED PERFORMANCE
- H SHIP SIZE AND INHERENT CONTROLLABILITY
- I SPEED EFFECTS ON INHERENT CONTROLLABILITY
- J SHIP RESPONSE DATA FOR THE 52,000 DWT SHIP

APPENDIX A

CHARACTERISTICS OF THE USCG/SA SIMULATOR

The simulator used for this experiment is located at Ship Analytics, Inc. in North Stonington, Connecticut. Its visual capability was developed for the U.S. Coast Guard for the Performance of Aids to Navigation Project. The components of the simulator are illustrated in Figure A-1 and consist of the following:

1. The ship's bridge
2. Standard ship's controls
3. Ship's indicators
4. An advanced "radio aided" navigation display unit
5. Computer generated visual system
6. Host computer with requisite interface equipment
7. Postexercise data reduction facility

A.1 THE SHIP'S BRIDGE

The bridge is 15 feet 9 inches wide and 15 feet 6 inches deep with windows for viewing the visual scene. Additional facilities include a chart table with a ten drawer chart storage. The lighting on the bridge can be controlled, and total darkness can be achieved.

A.2 SHIP'S CONTROLS

The control mechanisms found in the bridge simulator are tied directly to the host computer, providing the proper inputs for ship's controls with resultant ship's motion incorporated in the visual image. These control mechanisms include the following:

1. A ship's wheel and helm unit
2. An engine order telegraph which provides control of the ship's engines both ahead and astern. Propeller rpm and ship acceleration are determined by ownship's dynamics programmed for the computer for each specific ship size.

A.3 SHIP'S INDICATORS

The indicators are also tied to the host computer to provide information to the pilot. They include the following:

1. Two gyro repeaters, one on the steering stand and one mounted with an azimuth circle.
2. A shaft rpm indicator
3. A rudder angle indicator
4. A ship's clock which has been modified to show scenario time

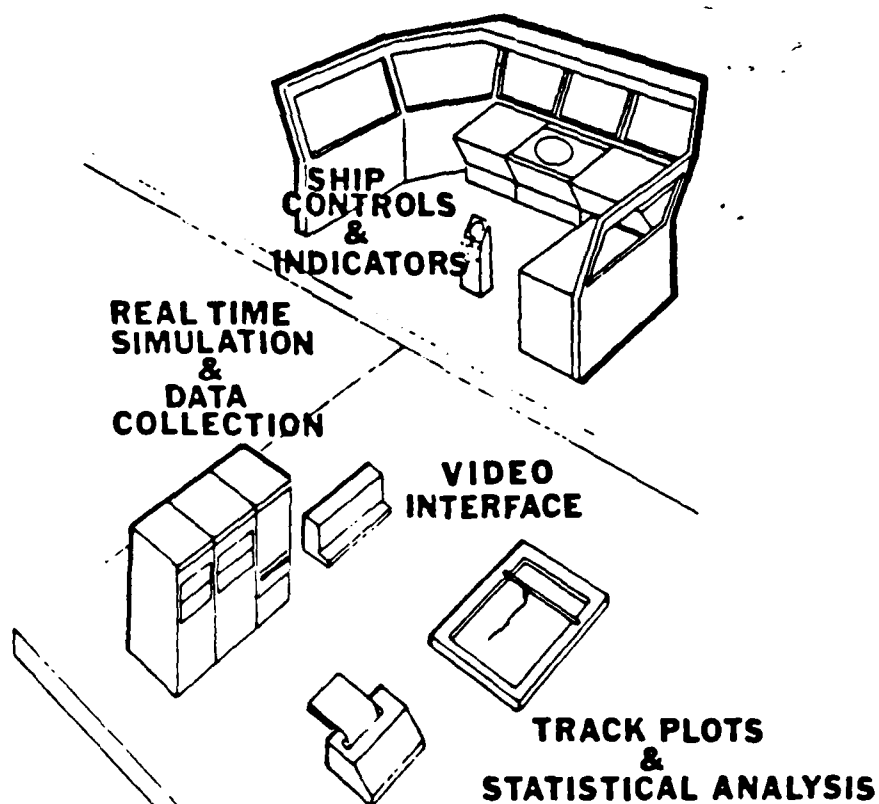


Figure A-1. USCG/EA Simulator

A.4 RADAR PPI

A 16-inch PPI simulating a generic 3 cm radar was developed and used for the earlier AN Radar I experiment.

A.5 NAVIGATION DISPLAY UNIT

The navigation display unit presents a variety of information displays to the pilot. It was used for radio aids experiments included in the U.S. Coast Guard Aids to Navigation Project, Phase II.

A.6 VISUAL SYSTEM

The visual system provides a 182-degree horizontal and a 20-degree vertical field of view. The dynamic scene for daytime conditions includes ownship's bow, the sky, water, and visible aids. The nighttime scene translates the aids into appropriate lights.

A.7 THE HOST COMPUTER

The host computer provides processing for the visual system consistent with ownship's characteristics, including maneuverability. The visibility conditions, the hydrodynamic model, and individual scenario topographical conditions are part of the initial conditions.

A.8 THE DATA REDUCTION CAPABILITY

Computer facilities are available to provide postexercise data reduction, analysis, and hard copy for individual scenarios or groups of scenarios.

Appendix B

SRA SUPPLEMENTAL EXPERIMENT: INSTRUCTIONS TO THE PILOT

INTRODUCTION

The purpose of this experiment is to supplement visual data collected from previous experiments. The conditions which will be evaluated include ship size, ship speed, channel width, buoy arrangement, lighting (day or night), and the environmental factors of wind and current.

Today you will run through a series of eight scenarios with three familiarization runs. The scenarios are grouped by ship size and ship speed with a "practice" familiarization run provided for each size ship. The scenarios are arranged in an approximate easy-to-hard order with two runs using a 30,000 dwt tanker, two runs using a 52,000 dwt tanker, and four runs using an 80,000 dwt tanker. Specific conditions of each scenario will be described before the run begins.

BRIDGE CONDITIONS

There will be:

- a helmsman on the bridge to receive your orders
- a gyrocompass, rpm indicator, rudder angle indicator, speed log
- an engine order telegraph which you must operate yourself, however, please announce speed changes if you make them
- charts and a current diagram
- no radar

It is important that you stay at the center of the bridge. It is only there that the buoy lights appear in the proper location and perspective.

MANEUVERING INSTRUCTIONS

For all scenarios, please move the ship to the centerline as quickly as you think prudent. Stay as close to a strictly defined "centerline" as you think practical. You may leave the centerline when you decide it is necessary for the approach to the turn. Use your own strategy to negotiate the turn. You may increase the speed in the turn if you think it is necessary. However, please return to the original scenario speed as soon as possible. In the second leg, return to the centerline as soon as possible and maintain it until the end of the run. See Figure A-1 for a review of maneuvering instructions. There is a chart available for each scenario.

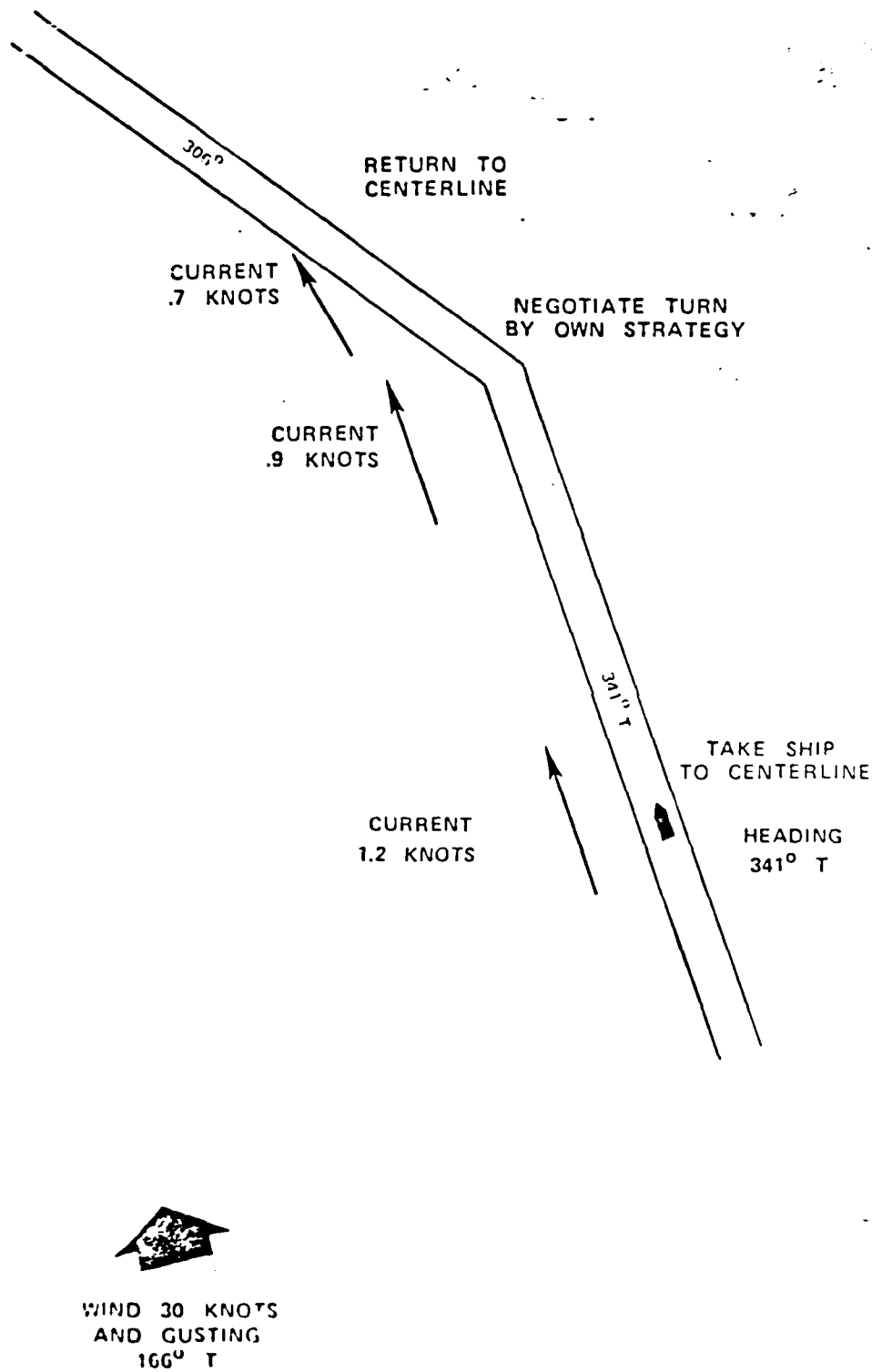


Figure B-1

FAMILIARIZATION WITH THE 30,000 DWT TANKER

Ship. The 30,000 dwt loaded tanker is 595 feet long with an 84-foot beam and a 35-foot draft. It has a split house with a midship bridge that puts the height of eye 45 feet above the water. The ship characteristics are described in Table A-1. A speed of approximately 7 knots over the water could be maintained throughout the run.

Channel and Buoy Markings. The channel in which the ship will transit is 500 feet wide with a 35-degree turn to the left with no cutoff. The depth of the channel allows minimal, but acceptable, clearance for the ship's keel. There are shallow water effects but no bank effects. The straight legs of the channel are marked by gated buoys spaced at 5/8 nm intervals. The turn is marked by four buoys. Please review the scenario chart before the familiarization run begins.

Lighting and Environmental Conditions. The scenario is run during the day with visibility at 3 nm. The current at the beginning of the turn has a set of 341 degrees true and a drift of 1.4 knots. It moves up the first leg of the channel, decreasing to 0.7 knots at the completion of turn. The current is broad on the port quarter at the turn pullout, then gradually turns to follow the second leg of the channel. The current continues to decrease until the end of the turn. There is a gusting wind averaging 30 knots throughout the scenario. Its direction averages 166 degrees true during the turn. The scenario chart identifies location and intensity of the wind and current.

Initialization and Duration. The ship will be initialized 1.3 nm below the turn and 100 feet to the right of the centerline. It will have a heading of 341 degrees true and speed through the water of approximately 7 knots. When you feel comfortable handling this vessel, you may request that the scenario be terminated.

Maneuvering Instructions. When you take control, please move the ship to the centerline as quickly as you think prudent. Stay as close to a strictly defined "centerline" as you think practical. You may leave the centerline when you decide it is necessary for the approach to the turn. Use your own strategy to negotiate the turn. You may increase the speed in the turn if you think it is necessary. However, please return to the original scenario speed as soon as possible. In the second leg, return to the centerline as soon as possible and maintain it until the end of the turn. See Figure A-1 for a review of maneuvering instructions.

Please feel free to ask questions or make comments at any time.

TABLE A-1



30,000 DWT VESSEL
WITH MIDSHIP BRIDGE

| SHIP CHARACTERISTICS | |
|----------------------|--------|
| DWT | 30,000 |
| LENGTH | 595 FT |
| BEAM | 84 FT |
| DRAFT | 35 FT |

| ENGINE ORDER | RPM | SPEED |
|-----------------|-----|-------|
| DEAD SLOW AHEAD | 20 | 3.4 |
| SLOW AHEAD | 40 | 6.8 |
| HALF AHEAD | 65 | 11.0 |
| FULL AHEAD | 85 | 14.4 |
| SEA SPEED | 105 | 17.8 |



52,000 DWT VESSEL
WITH REAR BRIDGE

| SHIP CHARACTERISTICS | |
|----------------------|--------|
| DWT | 52,000 |
| LENGTH | 653 FT |
| BEAM | 106 FT |
| DRAFT | 39 FT |

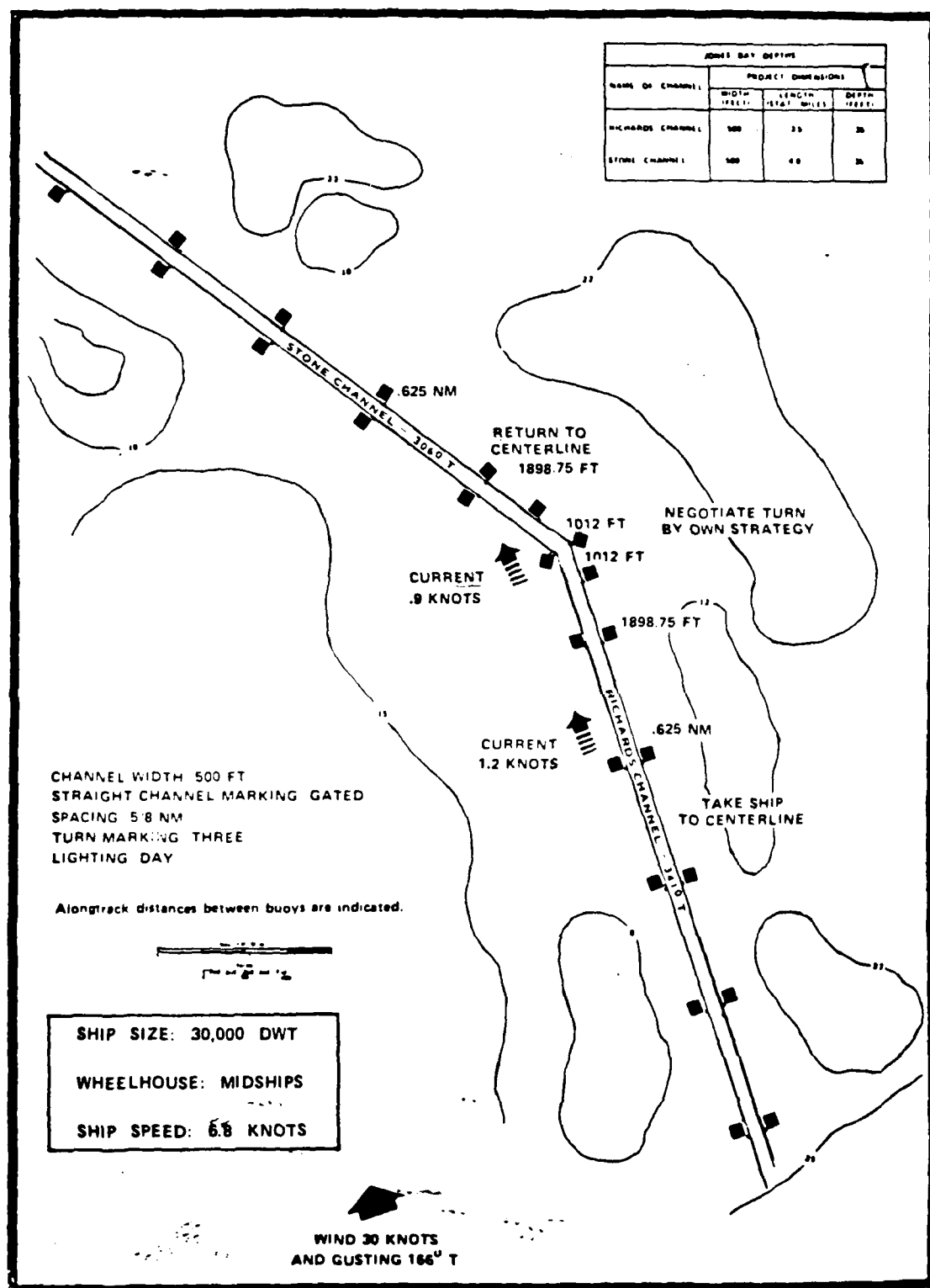
| ENGINE ORDER | RPM | SPEED |
|-----------------|-----|-------|
| DEAD SLOW AHEAD | 20 | 3.7 |
| SLOW AHEAD | 40 | 7.3 |
| HALF AHEAD | 60 | 11.0 |
| FULL AHEAD | 80 | 14.6 |
| SEA SPEED | 90 | 16.5 |



80,000 DWT VESSEL
WITH REAR BRIDGE

| SHIP CHARACTERISTICS | |
|----------------------|--------|
| DWT | 80,000 |
| LENGTH | 763 FT |
| BEAM | 125 FT |
| DRAFT | 40 FT |

| ENGINE ORDER | RPM | SPEED |
|-----------------|-----|-------|
| DEAD SLOW AHEAD | 20 | 3.0 |
| SLOW AHEAD | 45 | 6.9 |
| HALF AHEAD | 75 | 11.6 |
| FULL AHEAD | 100 | 15.4 |
| SEA SPEED | 120 | 18.5 |



30,000 DWT FAMILIARIZATION

RUN 1: SCENARIO 10

SHIP: 30,000 dwt ship with wheelhouse midships

SPEED: 65 rpm, 11 knots

CHANNEL 500 feet wide
Initialized 1.3 nm before turn
100 feet right of centerline
Terminated 1.25 nm beyond the turn

BUOY ARRANGEMENT: Straight legs: Gated buoys at 1-1/4 nm intervals
Turn: 3 buoy

LIGHTING: Day

VISIBILITY: 1-1/2 nm

DESIGN CONDITIONS: No wind and no current
10-foot clearance for ship's keel

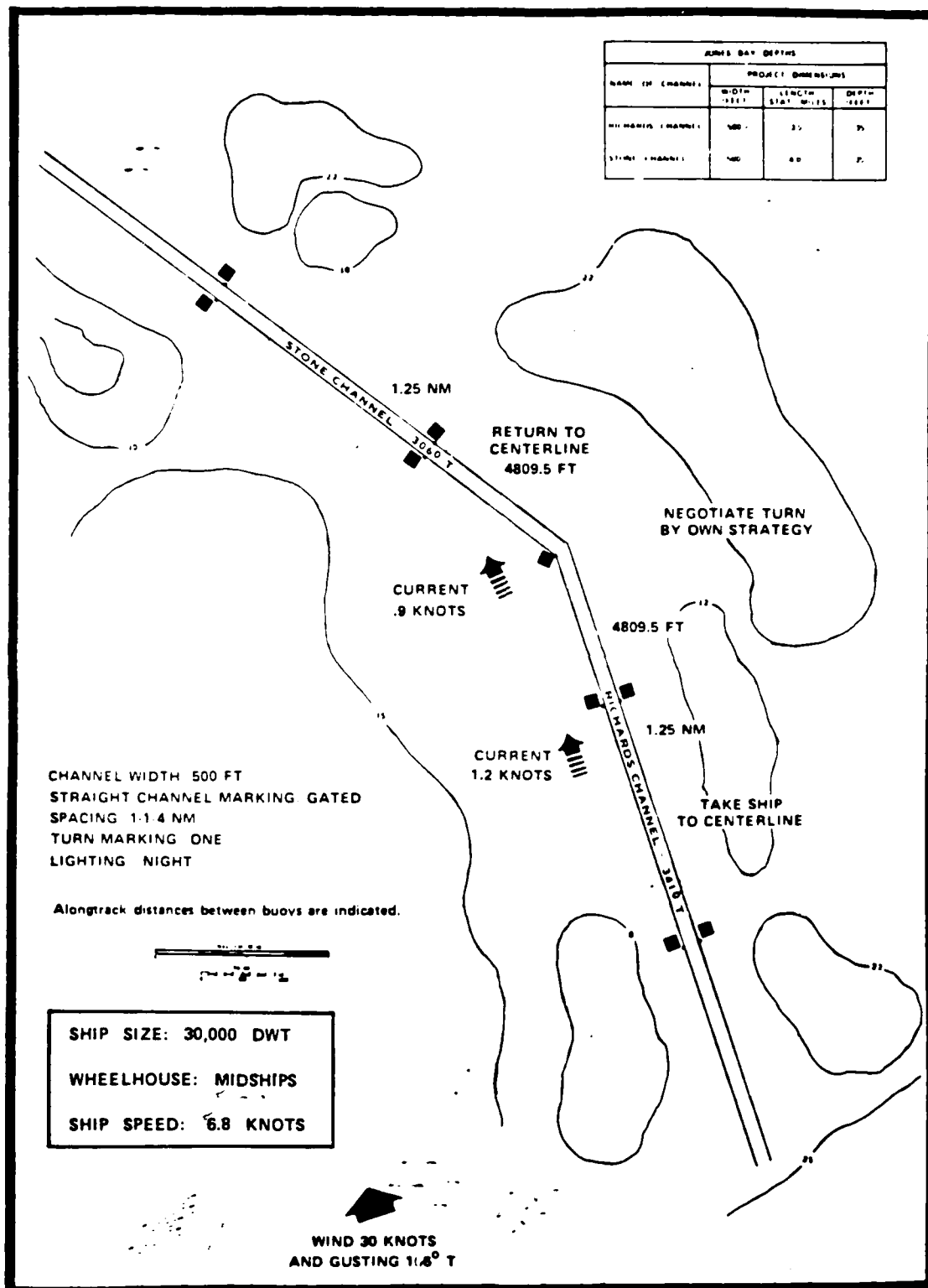
MANEUVERING INSTRUCTIONS: Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible.

| JAMES EARL RAYBURN | | | |
|-----------------------------|-----------------------|----------------------|----------------|
| NAME OF (MATERIAL) | PRODUCT ORIGIN NUMBER | | |
| | WIDEN -0011 | LENGTH -0101 0011 | DEPTH -0011 |
| WIDEN MATERIAL : MATERIAL : | 000 | 10 | 01 |
| LENGTH : MATERIAL : | 000 | 011 | 01 |

CHANNEL WIDTH 500 FT
STRAIGHT CHANNEL MARKING GATED
SPACING 1.1-4 NM
TURN MARKING THREE
LIGHTING DAY
NO WIND AND CURRENT
Alongtrack distances between buoys are indicated.

SHIP SIZE: 30,000 DWT
WHEELHOUSE: MIDSHIPS
SHIP SPEED: 11 KNOTS

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RUN 2: | SCENARIO 9 |
| SHIP: | 30,000 dwt ship with wheelhouse midships |
| SPEED: | 40 rpm, 6.8 knots |
| CHANNEL | 500 feet wide Initialized 1.3 nm before turn 100 feet right of centerline Terminated 2.34 nm beyond the turn |
| BUOY ARRANGEMENT: | Straight legs: Gated buoys at 1-1/4 nm intervals Turn: 1 buoy |
| LIGHTING: | Night |
| VISIBILITY: | 1-1/2 nm |
| DESIGN CONDITIONS: | Wind and current as described in the familiarization run and as shown on the chart. There is a minimal, but acceptable, clearance for ship's keel. |
| MANEUVERING INSTRUCTIONS: | Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible. |



SCENARIO 9

R.C

FAMILIARIZATION WITH THE 52,000 DWT TANKER

Ship. The 52,000 dwt loaded tanker is 653 feet long with a 106-foot beam and a 39-foot draft. It has a rear house that puts the height of eye 50 feet above the water. The characteristics are described in Table A-1. Speed of approximately 7 knots over the water should be maintained throughout the turn.

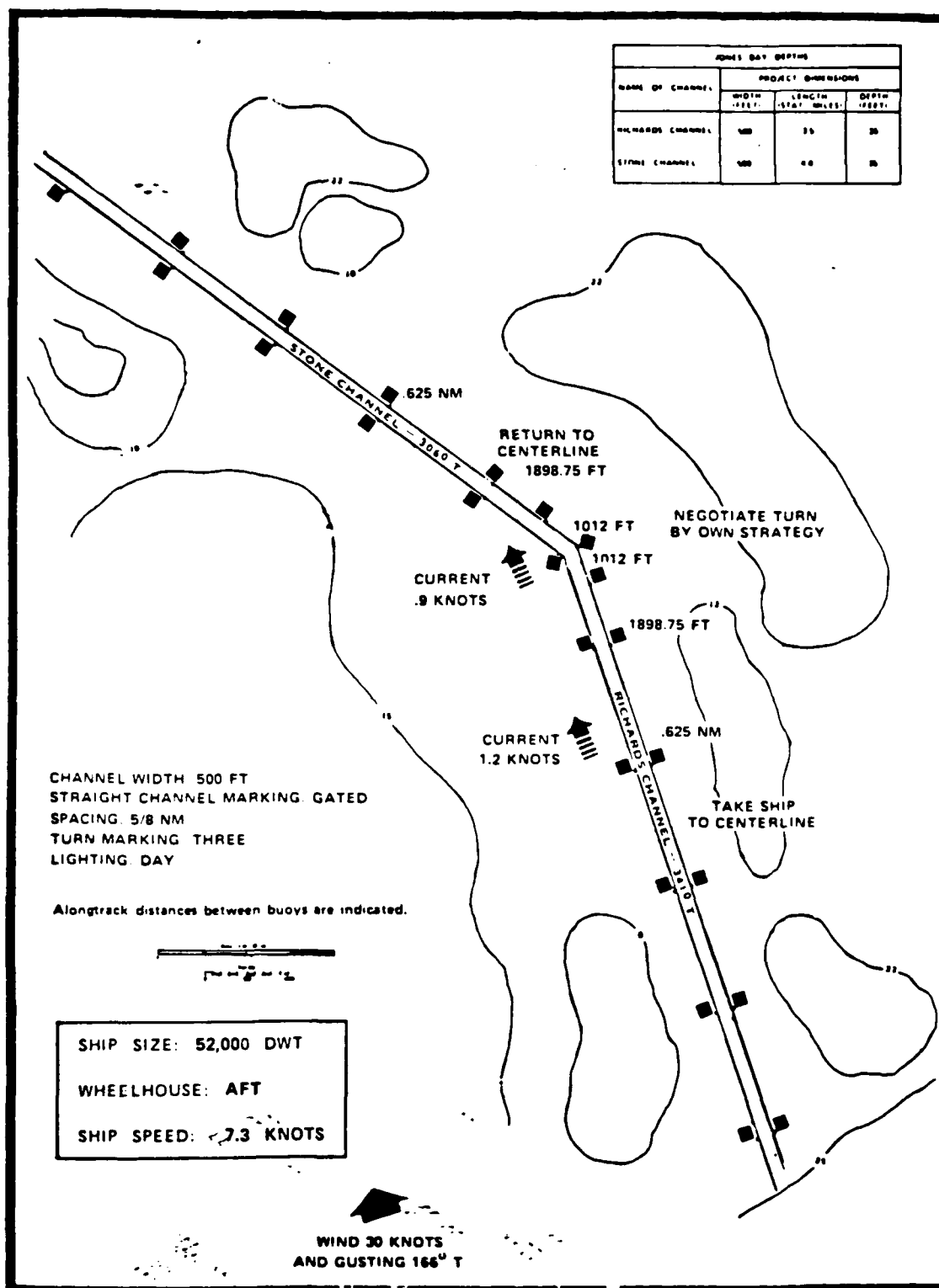
Channel and Buoy Markings. The channel in which the speed will transit is 500 feet wide with a 35-degree turn to the left with no cutoff. The depth of the channel allows minimal, but acceptable clearance for the ship's keel. There are shallow water effects but no bank effects. The straight legs of the channel are marked by gated buoys spaced at 5/8 nm intervals. The turn is marked by four buoys. Please review the scenario chart before the familiarization run begins.

Lighting and Environmental Conditions. This scenario is run during the day with visibility at 3 nm. The current at the beginning of the turn has a set of 341 degrees true and a drift of 1.4 knots. It moves up the first leg of the channel, decreasing to 0.7 knots at the completion of the turn. The current is broad on the port quarter at the turn pullout. The current continues to decrease until the end of the turn. There is a gusting wind averaging 30 knots throughout the scenario. Its direction averages 166 degrees true during the turn. The scenario chart identifies location and intensity of the wind and current.

Initialization and Duration. The ship will be initialized 1.3 nm below the turn and 100 feet to the right of the centerline. It will have a heading of 341 degrees true and speed through the water of approximately 7 knots. When you feel comfortable handling this vessel, you may request that the scenario be terminated.

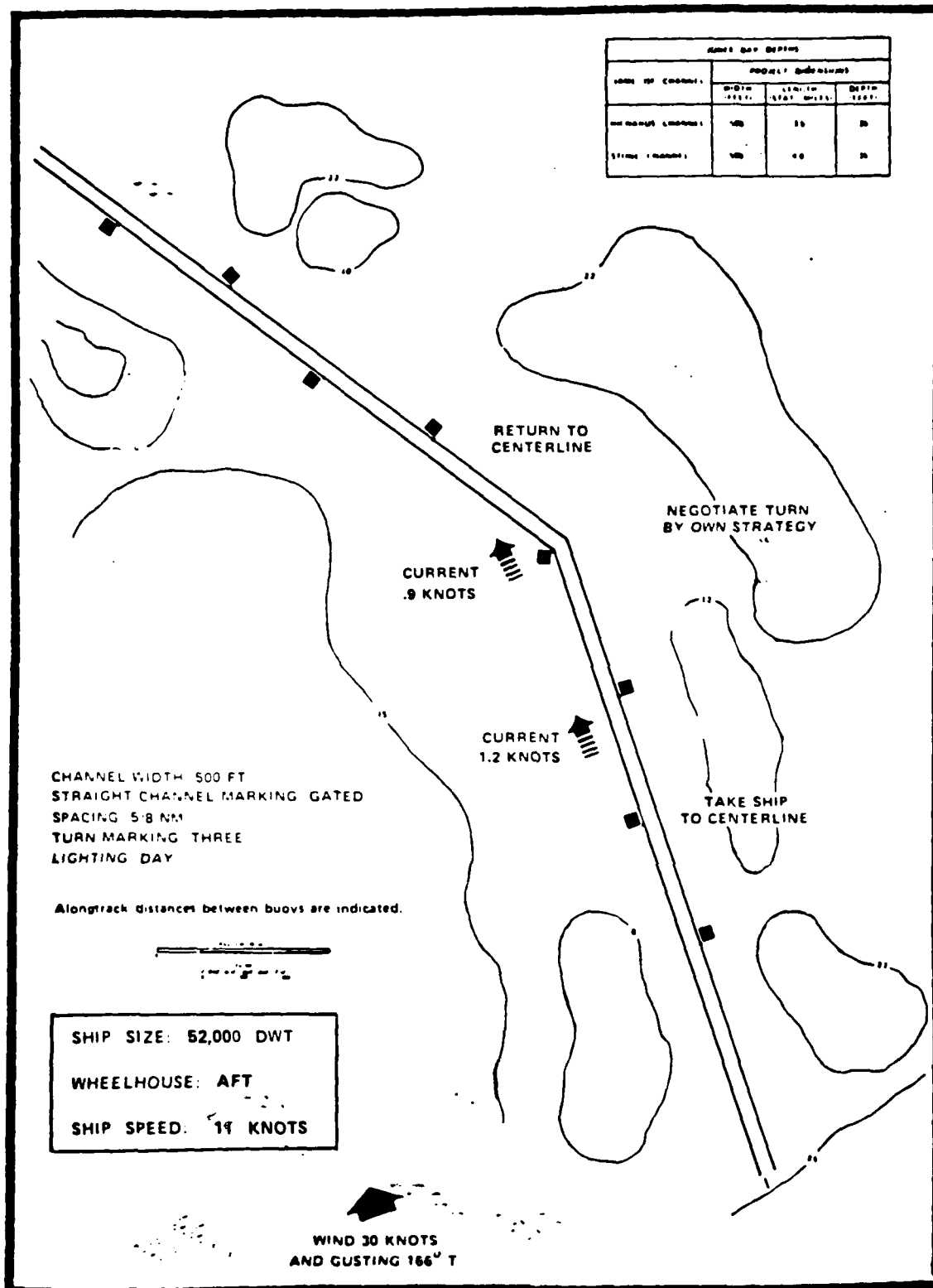
Maneuvering Instructions. When you take control, please move the hp to the centerline as quickly as you think prudent. Stay as close to a strictly defined "centerline" as you think practical. You may leave the centerline when you decide it is necessary for the approach to the turn. Use your own strategy to negotiate the turn. You may increase the speed in the turn if you think it is necessary. However, please return to the original scenario speed as soon as possible. In the second leg, return to the centerline as soon as possible and maintain it until the end of the run. See Figure A-1 for a review of maneuvering instructions.

Please feel free to ask questions or make comments at any time.



52,000 DWT FAMILIARIZATION

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RUN 3: | SCENARIO 12 |
| SHIP: | 52,000 dwt ship with wheelhouse aft |
| SPEED: | 60 rpm, 11 knots |
| CHANNEL | 500 feet wide Initialized 1.3 nm before turn 100 feet right of centerline Terminated 2.34 nm beyond the turn |
| BUOY ARRANGEMENT: | Straight legs: Staggered buoys at 1-1/4 nm intervals Turn: 1 buoy |
| LIGHTING: | Day |
| VISIBILITY: | 1-1/2 nm |
| DESIGN CONDITIONS: | Wind and current as described in the familiarization run and as shown on the chart. There is a minimal, but acceptable, clearance for ship's keel. |
| MANEUVERING INSTRUCTIONS: | Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible. |



SCENARIO 12

RUN 4: SCENARIO 11

SHIP: 52,000 dwt ship with wheelhouse aft

SPEED: 40 rpm, 7.3 knots

CHANNEL 500 feet wide
Initialized 1.3 nm before turn
100 feet right of centerline
Terminated 2.34 nm beyond the turn

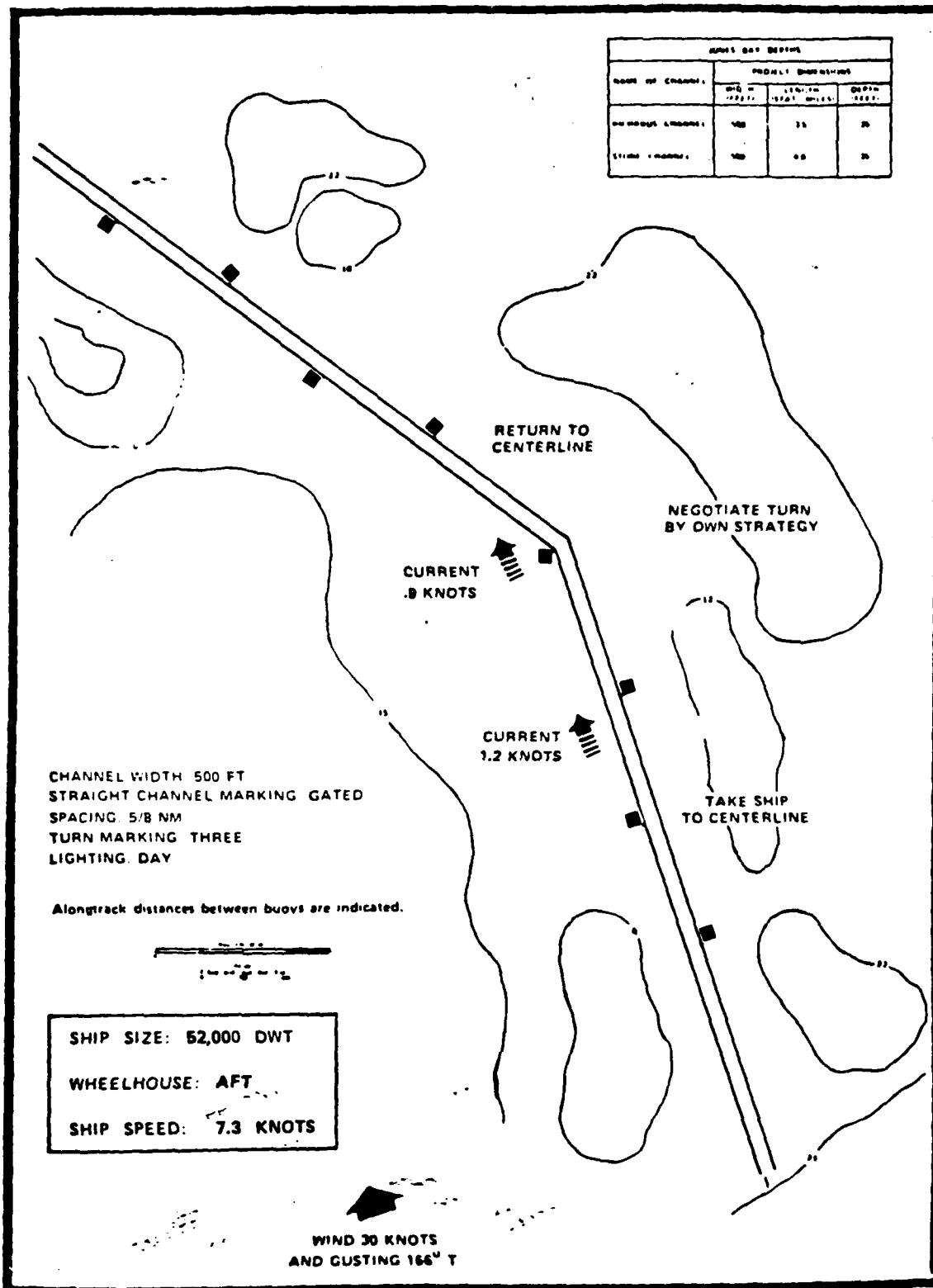
BUOY ARRANGEMENT: Straight legs: Staggered buoys at 1-1/4 nm intervals
Turn: 1 buoy

LIGHTING: Day

VISIBILITY: 1-1/2 nm

DESIGN CONDITIONS: Wind and current as described in the familiarization run and as shown on the chart. There is a minimal, but acceptable, clearance for ship's keel.

MANEUVERING INSTRUCTIONS: Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible.



SCENARIO 11

FAMILIARIZATION WITH THE 80,000 DWT BULK CARRIER

Ship. The 80,000 dwt loaded bulk carrier is 763 feet long with an 125-foot beam and a 40-foot draft. It has a rear bridge that puts the height of eye 80 feet above the water. The ship characteristics are described in Table A-1. A speed of approximately 7 knots over the water should be maintained throughout the run.

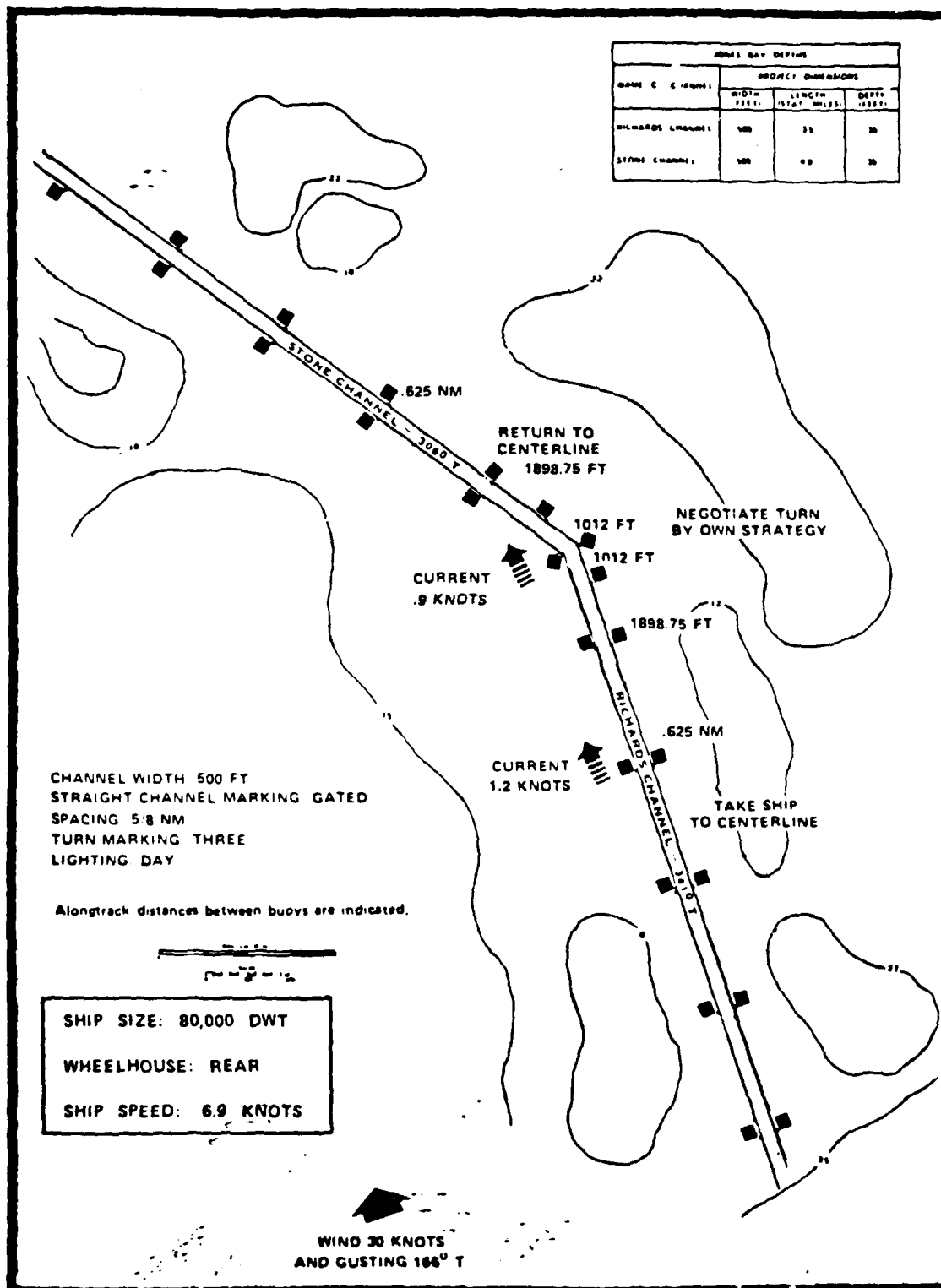
Channel and Buoy Markings. The channel in which the ship will transit is 500 feet wide with a 35-degree turn to the left with no cutoff. The depth of the channel allows minimal, but acceptable, clearance for the ship's keel. There are shallow water effects but no bank effects. The straight legs of the channel are marked by gated buoys spaced at 5/8 nm intervals. The turn is marked by four buoys. Please review the scenario chart before the familiarization run begins.

Lighting and Environmental Conditions. This scenario is run during the day with visibility at 1-1/2 nm. The current at the beginning of the run has a set of 341 degrees true and a drift of 1.4 knots. It moves up the first leg of the channel, decreasing to 0.7 knots at the completion of turn. The current is broad on the port quarter at the turn pullout, then gradually turns to follow the second leg of the channel. The current continues to decrease until the end of the turn. There is a gusting wind averaging 30 degrees throughout the scenario. Its direction averages 166 degrees true during the turn. The scenario chart identifies location and intensity of the wind and current.

Initialization and Duration. The ship will be initialized 1.3 nm below the turn and 100 feet to the right of the centerline. It will have a heading of 341 degrees true and speed through the water of approximately 7 knots. When you feel comfortable handling this vessel, you may request that the scenario be terminated.

Maneuvering Instructions. When you take control, please move the ship to the centerline as quickly as you think prudent. Stay as close to a strictly defined "centerline" as you think practical. You may leave the centerline when you decide it is necessary for the approach to the turn. Use your own strategy to negotiate the turn. You may increase the speed in the turn if you think it is necessary. However, please return to the original scenario speed as soon as possible. In the second leg, return to the centerline as soon as possible and maintain it until the end of the turn. See Figure A-1 for a review of maneuvering instructions.

Please feel free to ask questions or make comments at any time.



80,000 DWT FAMILIARIZATION

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RUN 5: | SCENARIO 5 |
| SHIP: | 80,000 dwt ship with wheelhouse aft |
| SPEED: | 75 rpm, 11.6 knots |
| CHANNEL | 500 feet wide Initialized 1.3 nm before turn 100 feet right of centerline Terminated 2.34 nm beyond the turn |
| BUOY ARRANGEMENT: | Straight legs: Gated buoys at 5/8 intervals Turn: 3 buoys |
| LIGHTING: | Day |
| VISIBILITY: | 1-1/2 nm |
| DESIGN CONDITIONS: | Wind and current as described in the familiarization run and as shown on the chart. There is a minimal, but acceptable, clearance for ship's keel. |
| MANEUVERING INSTRUCTIONS: | Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible. |

RUN 7: SCENARIO 8

SHIP: 80,000 dwt ship with wheelhouse aft

SPEED: 45 rpm, 6.9 knots

CHANNEL 500 feet wide
Initialized 1.3 nm before turn
100 feet right of centerline
Terminated 2.34 nm beyond the turn

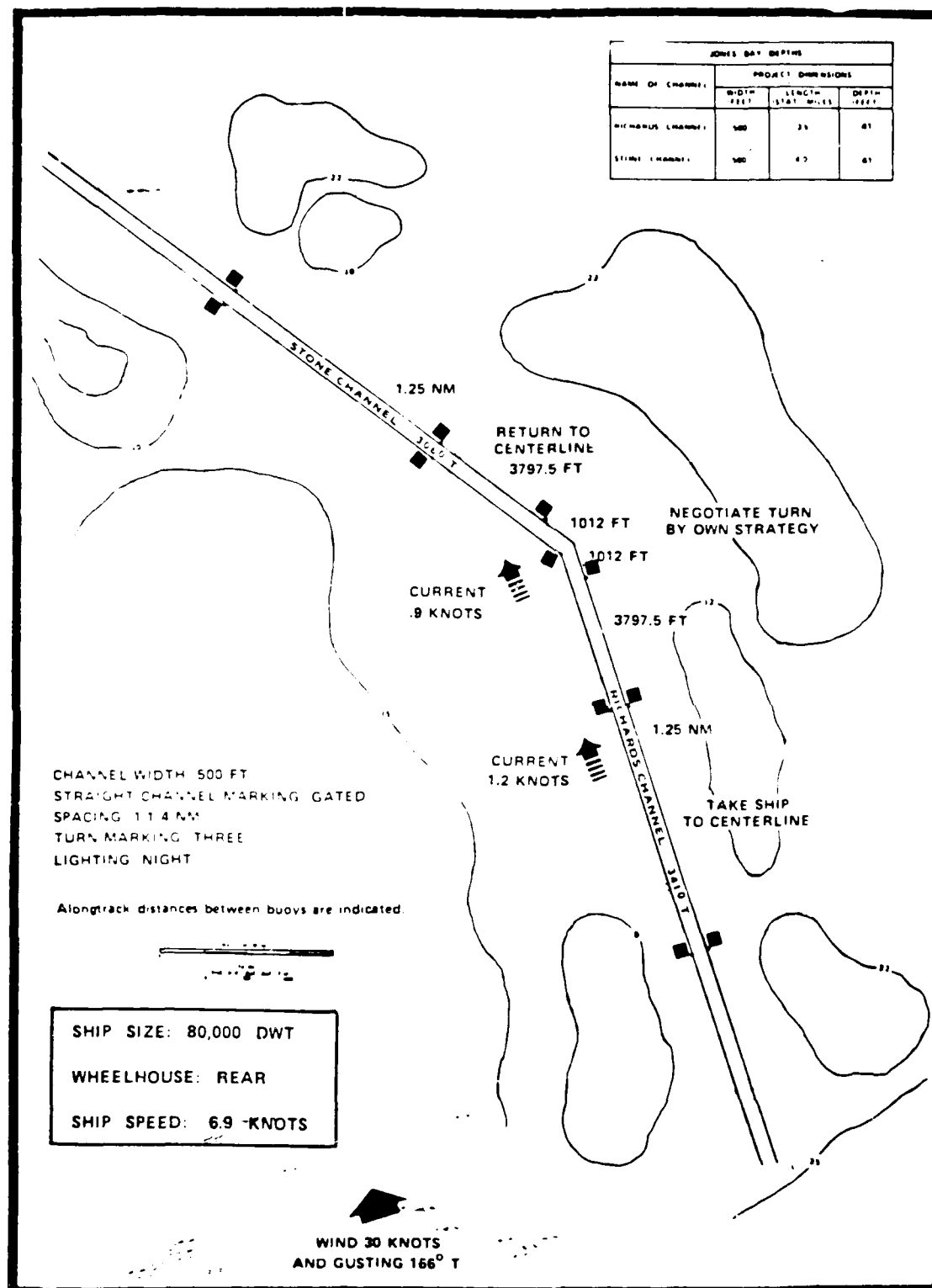
BUOY ARRANGEMENT: Straight legs: Gated buoys at 1-1/4 nm intervals
Turn: 3 buoys

LIGHTING: Night

VISIBILITY: 1-1/2 nm

DESIGN CONDITIONS: Wind and current as described in the familiarization run and as shown on the chart. There is a minimal, but acceptable, clearance for ship's keel.

MANEUVERING INSTRUCTIONS: Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible.



SCENARIO 8

RUN 6: SCENARIO 7

SHIP: 80,000 dwt ship with wheelhouse aft

SPEED: 45 rpm, 6.9 knots.

CHANNEL 500 feet wide
Initialized 1.3 nm before turn
100 feet right of centerline
Terminated 1.25 nm beyond the turn

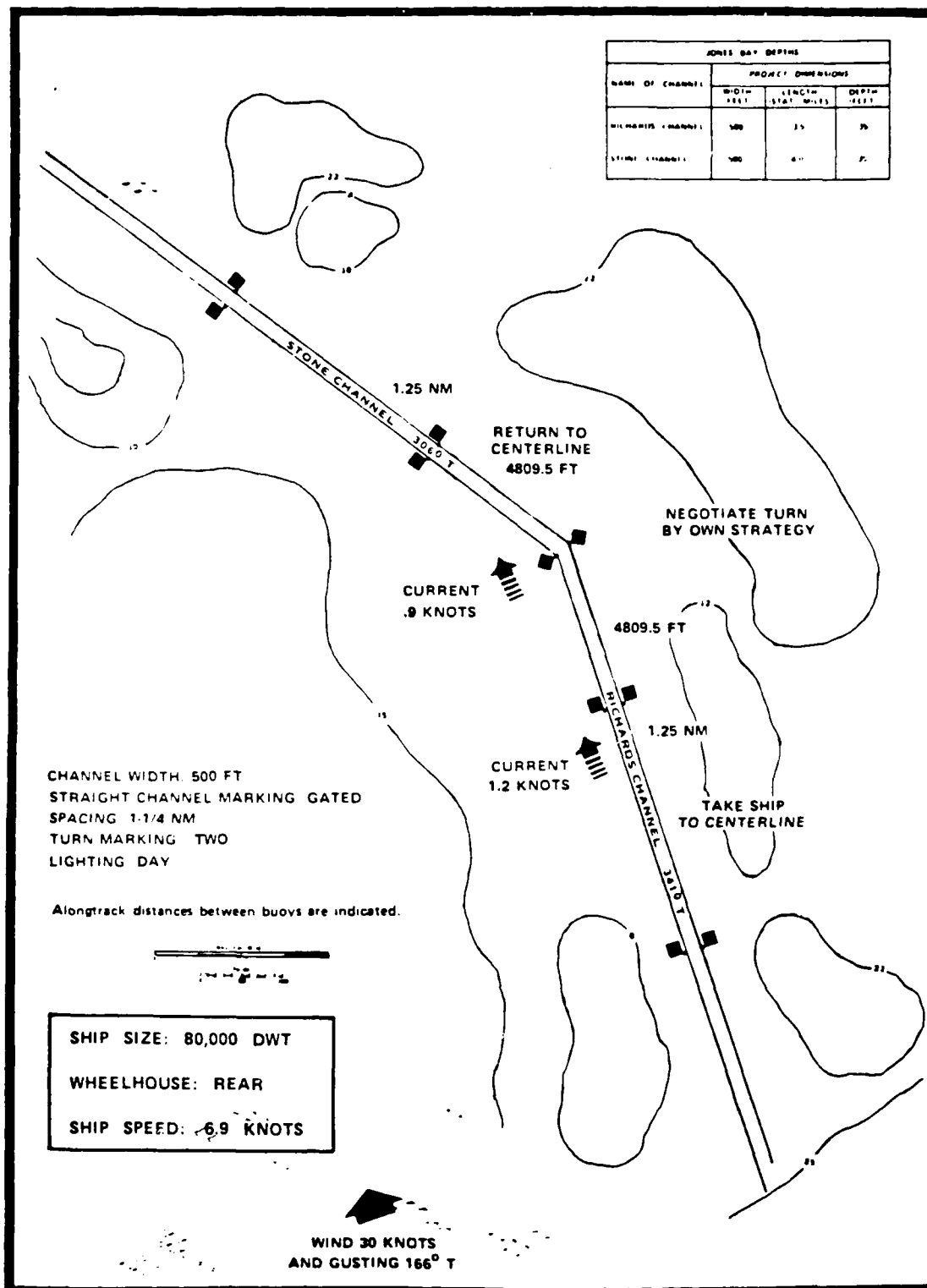
BUOY ARRANGEMENT: Straight legs: Gated buoys at 1-1/4 nm intervals
Turn: 2 buoys

LIGHTING: Day

VISIBILITY: 1-1/2 nm

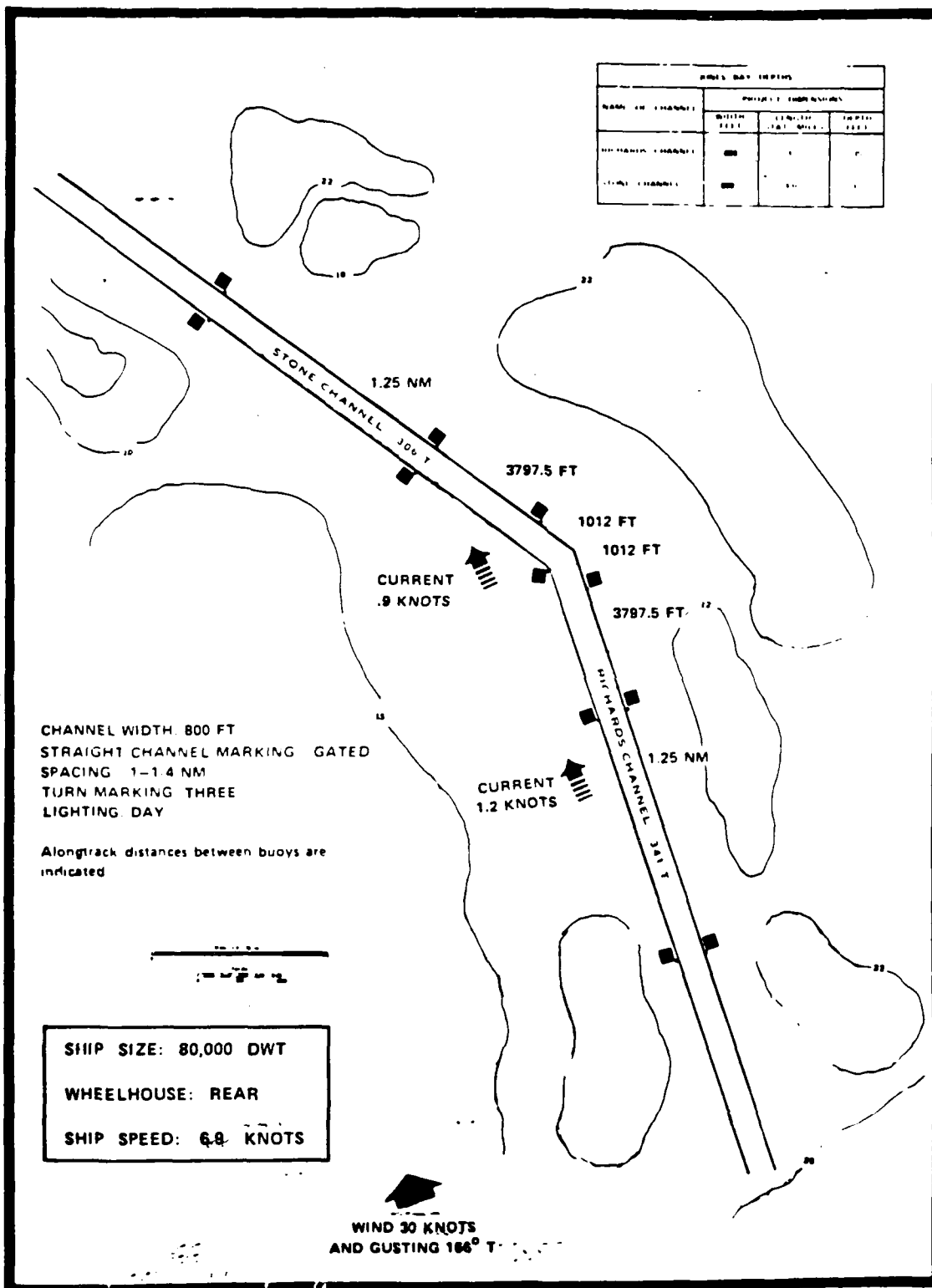
DESIGN CONDITIONS: Wind and current as described in the familiarization run and as shown on the chart. There is a minimal, but acceptable, clearance for ship's keel.

MANEUVERING INSTRUCTIONS: Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible.



SCENARIO 7

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RUN 8: | SCENARIO 6 |
| SHIP: | 80,000 dwt ship with wheelhouse aft |
| SPEED: | 45 rpm, 6.9 knots |
| CHANNEL | 800 feet wide Initialized 1.3 nm before turn 100 feet right of centerline Terminated 2.34 nm beyond the turn |
| BUOY ARRANGEMENT: | Straight legs: Gated buoys at 1-1/4 nm intervals Turn: 3 buoys |
| LIGHTING: | Day |
| VISIBILITY: | 1-1/2 nm |
| DESIGN CONDITIONS: | Wind and current as described in the familiarization run and as shown on the chart. There is a minimal, but acceptable, clearance for ship's keel. |
| MANEUVERING INSTRUCTIONS: | Same as in familiarization run. Maintain the centerline, and use your own strategy to negotiate the turn. You may change speed in the turn, however, resume starting speed as soon as possible. |

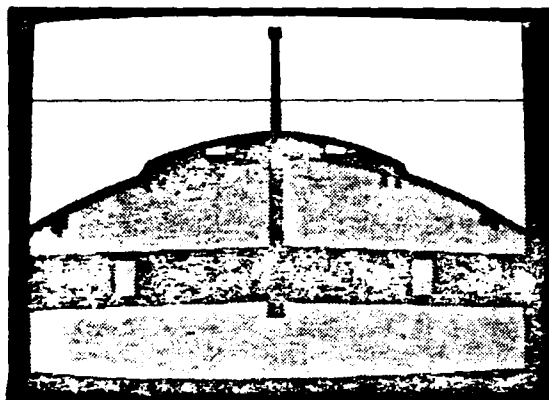


SCENARIO 6

Appendix C
PILOTED PERFORMANCE AS A FUNCTION OF SHIP SIZE

C.1 DESCRIPTION OF SHIPS

Three ships were simulated in this experiment. The 30,000 dwt tanker is identical to that used in the Ship Variables²⁶ and other experiments. The bow image and ship particulars for the 30,000 dwt vessel are shown by Figure C-1. The ship is 595 feet long with an 84-foot beam, and a 35-foot draft. It was run in a channel with a 1-foot underkeel clearance which makes it relatively difficult to handle for its size. It has a split house with a midship bridge that puts the eyepoint 223 feet back from the bow, 75 feet ahead of the center of gravity, and 45 feet above the water.



| SHIP CHARACTERISTICS | |
|----------------------|--------|
| DWT | 30,000 |
| LENGTH | 595 FT |
| BEAM | 84 FT |
| DRAFT | 35 FT |

| ENGINE ORDER | RPM | SPEED |
|-----------------|-----|-------|
| DEAD SLOW AHEAD | 20 | 3.4 |
| SLOW AHEAD | 40 | 6.8 |
| HALF AHEAD | 65 | 11.0 |
| FULL AHEAD | 85 | 14.4 |
| SEA SPEED | 105 | 17.8 |

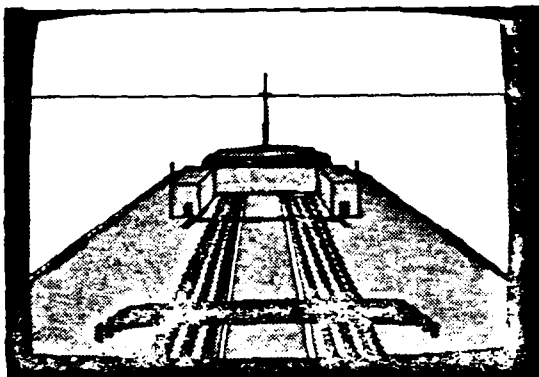


30,000 DWT VESSEL
WITH MIDSHIP BRIDGE

Figure C-1. 30,000 dwt Ship Bow Image and Ship Particulars

The second ship simulated in this experiment was a 52,000 dwt tanker. This ship is new to the project and was selected to provide additional ship size data. The bow image and ship particulars for the 52,000 dwt vessel are shown by Figure C-2. The tanker is 653 feet long with a 106 foot beam and 39-foot draft. It was also run in a channel with a 1-foot underkeel clearance to make the ship more difficult to handle. It has a rear wheelhouse that puts the eyepoint 575 feet back from the bow, 110 feet forward of the stern, and 55 feet above the water.

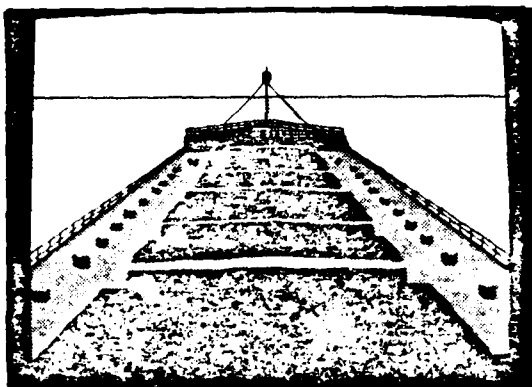
²⁶W.R. Bertsche, D.A. Atkins, and M.W. Smith, op. cit.



| SHIP CHARACTERISTICS | |
|----------------------|--------|
| DWT | 52,000 |
| LENGTH | 653 FT |
| BEAM | 106 FT |
| DRAFT | 39 FT |

| ENGINE ORDER | RPM | SPEED |
|-----------------|-----|-------|
| DEAD SLOW AHEAD | 20 | 3.7 |
| SLOW AHEAD | 40 | 7.3 |
| HALF AHEAD | 60 | 11.0 |
| FULL AHEAD | 80 | 14.6 |
| SEA SPEED | 90 | 16.5 |

52,000 DWT VESSEL
WITH REAR BRIDGE



| SHIP CHARACTERISTICS | |
|----------------------|--------|
| DWT | 80,000 |
| LENGTH | 763 FT |
| BEAM | 125 FT |
| DRAFT | 40 FT |

| ENGINE ORDER | RPM | SPEED |
|-----------------|-----|-------|
| DEAD SLOW AHEAD | 20 | 3.0 |
| SLOW AHEAD | 45 | 6.5 |
| HALF AHEAD | 75 | 11.6 |
| FULL AHEAD | 100 | 15.4 |
| SEA SPEED | 120 | 18.5 |

80,000 DWT VESSEL
WITH REAR BRIDGE

Figure C-2. 52,000 and 80,000 dwt Ship Bow Images and Ship Particulars

The third ship simulated in this experiment was an 80,000 dwt tanker. This ship is identical to the 80,000 dwt vessel used in the Ship Variables and other experiments. The bow image and ship particulars for the 80,000 dwt vessel are shown by Figure C-2. The vessel is 763 feet long with a 125-foot beam, and a 40-foot draft. It was also run in a channel with a 1-foot underkeel clearance that makes the ship more difficult to handle. The bridge is a rearhouse that places the eyepoint 732 feet back from the bow, 350 feet back from the center of gravity and 80 feet above the water.

For more information on the ships, see Appendices H, I, and J which discuss the effects of ship size and speed on controllability and provide ship response data for the 52,000 dwt ship.

C.2 LOW BUOY DENSITY AND SHIP SIZE

Scenario 11 which is part of this experiment was designed to be comparable to Scenarios 2 and 6 of the Ship Variables Experiment. The scenarios differ only by ship size with Ship Variables (SV) Scenario 2 using a 30,000 dwt tanker with the bridge midships, SRA Supplemental (SRA) Scenario 11 using a 52,000 dwt tanker with the bridge aft, and SV Scenario 6 using an 80,000 dwt tanker with the bridge aft. The constant conditions are identified by Table C-1.

TABLE C-1. CONSTANT CONDITIONS FOR LOW BUOY DENSITY AND SHIP SIZE COMPARISON

| | |
|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Channel dimensions: | <ul style="list-style-type: none"> • 500-foot width • 1-foot underkeel clearance • 35-degree noncutoff turn |
| 2. Environmental effects: | <ul style="list-style-type: none"> • following wind and current changing to port quarter • daytime • 1-1/2 nm visibility |
| 3. Ship speed: | <ul style="list-style-type: none"> • 6 knots |
| 4. Channel markings: | <ul style="list-style-type: none"> • staggered buoys spaced at 1-1/4 nm intervals along one side • 1 buoy marking the turn |

The effect of ship size and low buoy density is shown by Figure C-3 and Table C-2. In general, the pilots have no difficulty maneuvering the 30,000 dwt ship. With the the 52,000 dwt ship, the pilots make the turn without difficulty, but they have problems with the current setting the ship to the right of the channel. With the 80,000 dwt ship, there was a greater tendency to sail into the wind than the 52,000 dwt ship, and the pilots had maneuvering problems completing the turn with the ship's tracks skirting the channel boundary.

In Leg 1, the two Ship Variables scenarios (30,000 dwt and 80,000 dwt vessels) start further back from the turn and outside the channel so a sea buoy was used to get the ships into the channel. Therefore, the mean tracks from the SV scenarios reach the centerline sooner than SRA Scenario 11. The

standard deviation is high for the SV scenarios indicating that many piloting strategies were used to get the ships on the centerline. Although the standard deviations are significantly different, this is a result of the initialization conditions.

In the turn maneuver, as ship size increases, the pilots tend to "hug the buoy" and start the turn further to the left. With the larger ships, the pilots stay close to the only buoy marking the turn since with the bulk of the ship in front, they can keep the ship in the channel when making the turn. In the turn pullout, the mean track of the 80,000 dwt ship is worse and statistically different from that of the other ships. Significant differences between the ships are listed in Table C-2. With the 80,000 dwt ship, the pilots began the turn too late and as a result the mean track was approximately 140 feet to the right of the centerline as compared to approximately 70 feet for the 30,000 and 52,000 dwt ships. Although the variability of the tracks was not significantly different it was smallest for the 30,000, in the middle for the 52,000, and largest for the 80,000. Since the mean for the 80,000 was closer to the channel edge, some tracks exited the right channel boundary between Data Lines 2 and 5. Pilots make the turn best with the 30,000, with the larger ship the pullout is further off the centerline and closer to the right side of the channel.

Performance in Leg 2 was again best with the smaller ship. Although the mean track of the 30,000 dwt ship was set almost 90 feet to the right the standard deviation was only 60 feet as compared to the 52,000 dwt ship with the mean of almost 80 feet and a standard deviation of 90 feet. The pilots have no difficulty compensating for the current with the 30,000, however, the 52,000 dwt ship tracks were more widely spread with some tracks skirting the channel boundary. The standard deviation of the 52,000 track begins to narrow when the ship passes the first buoy after the turn. After this point, the 52,000 dwt ship tracks become more similar and less dispersed indicating that the pilots have the ship under control.

Performance with the 80,000 dwt ships is different from that of the other ships. Figure C-3 shows the tendency is greatest with the 80,000 for "buoy hopping." After the turn pullout, the mean track moves left to compensate for its position after the turn. Once the ship passes the first buoy after the turn, it continues left heading for the next buoy. When piloting with the 80,000 dwt ship the mean track is further left through most of Leg 2. This results from a combination of buoy hopping and the ship bow heading in the direction of the wind due to the sail effect. The "sail effect" on the ship can be estimated by comparing the "sail area" forward of the pivot point with the sail area abaft the pivot point. Since this effect is large, the wind will have a greater effect on the ship which will have a tendency to turn slowly into the wind.²⁷

It is surprising that as wind and current effects decrease, the standard deviation increases with the smaller ship while it decreases with the larger ships. It was expected that it would decrease with all ships. A wide stand-

²⁷Naval Institute Press. "Watch Officer's Guide - A Handbook for All Deck Officers," Tenth Edition, Naval Institute Press, Annapolis, Maryland.

TABLE C-2. STATICAL DIFFERENCES IN PILOTED PERFORMANCE
WITH 30K, 52K, AND 80K DWT SHIPS IN LEG 2

MEAN TRACKS IN SELECTED MANEUVERS IN LEG 2

| Ship Size | Turn Pullout | | Recovery | | Trackkeeping | |
|-----------|--------------|------|-----------|------|--------------|------|
| | Data Line | Mean | Data Line | Mean | Data Line | Mean |
| 30,000 | 3 | 72R | 7 | 88R | 22 | 25R |
| 52,000 | 3 | 71R | 7 | 77R | 20 | 23R |
| 80,000 | 3 | 137R | 6 | 88R | 22 | 69L |

Mean in feet to right or left of centerline

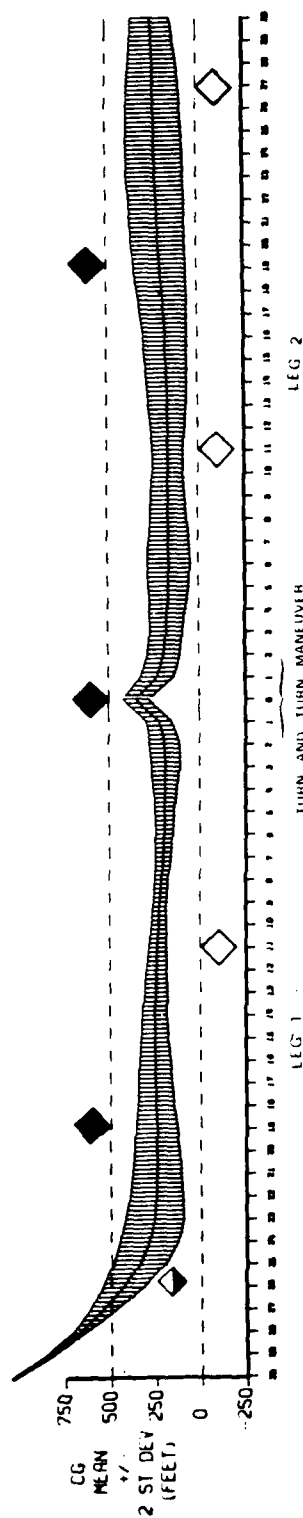
STANDARD DEVIATION OF TRACKS IN SELECTED MANEUVERS IN LEG 2

| Ship Size | Turn Pullout | | Recovery | | Trackkeeping | |
|-----------|--------------|--------------------|-----------|--------------------|--------------|--------------------|
| | Data Line | Standard Deviation | Data Line | Standard Deviation | Data Line | Standard Deviation |
| 30,000 | 3 | 45 | 6 | 60 | 22 | 77 |
| 52,000 | 3 | 54 | 9 | 91 | 30 | 48 |
| 80,000 | 3 | 65 | 12 | 78 | 28 | 56 |

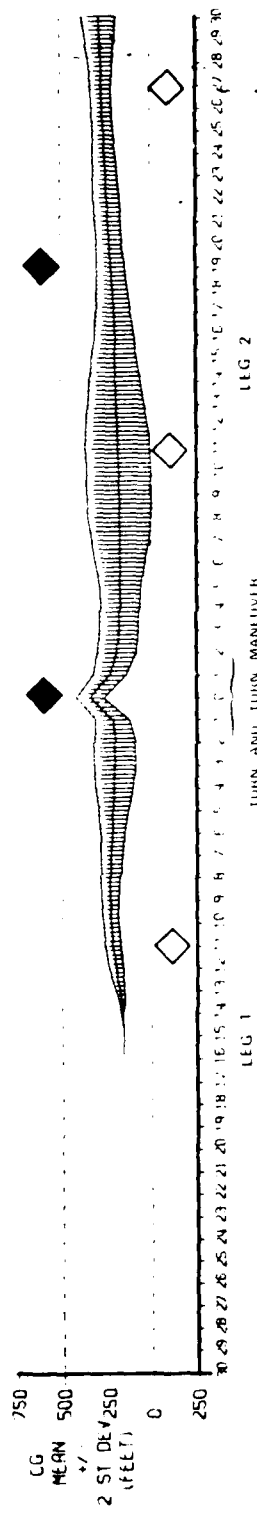
Standard deviation in feet

Arrows indicate statistically significant comparison at $p < 0.10$ (two-tailed test)

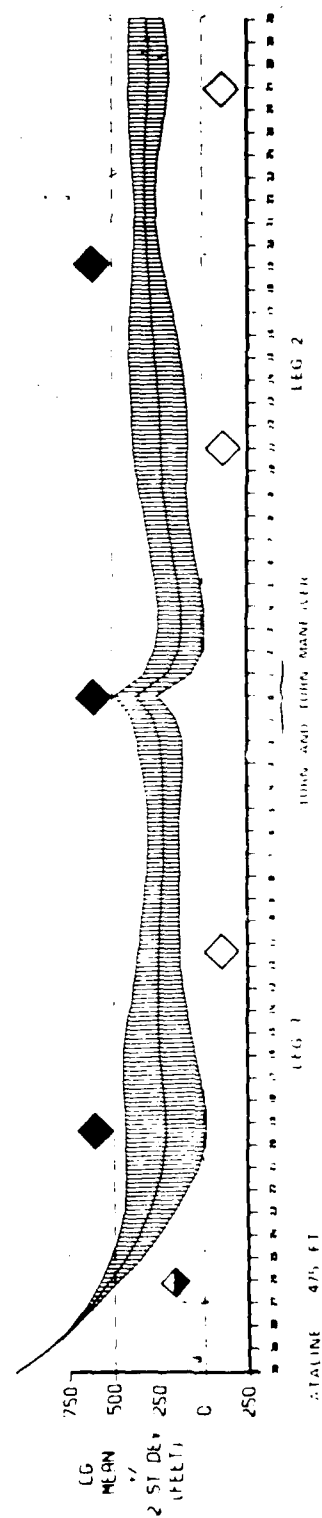
standard deviation implies two possibilities: (1) the pilots experience shiphandling problems or (2) the pilots are comfortable with the ship and are implementing different strategies. With the 30,000, the pilots easily maneuver the ship through the channel even during demanding tasks such as entering the channel by using a sea buoy and maneuvering for the 35-degree turn. Therefore, the significantly wider standard deviation in the "trackkeeping" portion of the scenario is due to pilots being "confident" with the ship and using different strategies in piloting and a "looser" definition of the centerline. -It is misleading to compare this track to that of the 52,000 and 80,000 dwt ships. These tracks are within 50 feet of the channel but from the scenario means it can be seen that the pilots are buoy hopping.



SV2: 30,000 DWT SHIP WITH MIDSHIP WHEELHOUSE



SRA11: 52,000 DWT SHIP WITH AFT WHEELHOUSE



SV6: 80,000 DWT SHIP WITH AFT WHEELHOUSE

Figure C-3. Effect of Ship Size and Low Buoy Density

C.3 HIGH BUOY DENSITY AND SHIP SIZE

The scenarios which evaluate the effect of high buoy density and ship size were taken from the Ship Variables Experiment. The scenarios differed only by ship size with SV 5 using a 30,000 dwt tanker with a midship bridge and SV 7 using a 80,000 dwt tanker with a bridge aft. The constant conditions are identified by Table C-3.

TABLE C-3. CONSTANT CONDITIONS FOR HIGH BUOY DENSITY AND SHIP COMPARISON

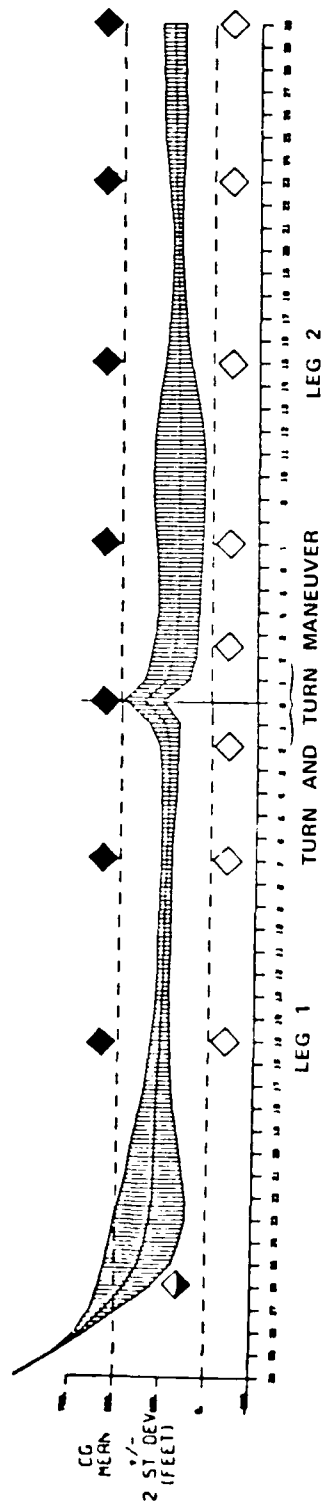
| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Channel dimensions: | <ul style="list-style-type: none">• 500-foot width• 1-foot under keel clearance• 35-degree noncutoff turn |
| 2. Environmental effects: | <ul style="list-style-type: none">• following wind and current changing to port quarter• daytime• 1-1/2 nm visibility |
| 3. Ship speed: | <ul style="list-style-type: none">• 6 knots |
| 4. Channel markings: | <ul style="list-style-type: none">• gated buoys spaced at 5/8 nm marking the straight legs• 3 buoys marking the turn |

Since no new data was collected to analyze the effect of high buoy density on ship size, performance differences will be summarized in this section. Section 5 of the Ship Variables Report discusses in detail the effect of high buoy density on performance with the 30,000 and 80,000 dwt vessels.

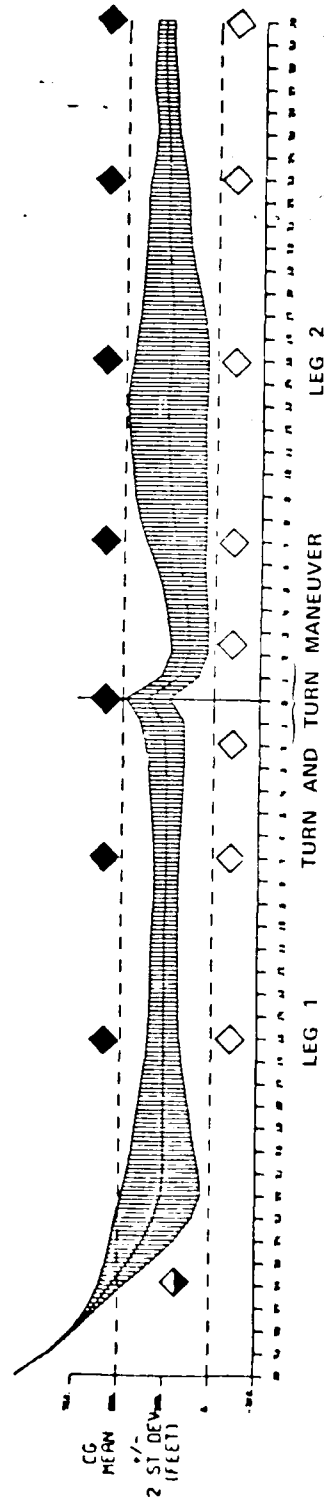
Both ships were piloted successfully in the high buoy density channel as indicated by Figure C-4. These data, however, indicate there is a general increase in crosstrack variation for the 80,000 dwt vessel. Comparison of the two conditions in both mean crosstrack location and standard deviation is shown in Figure C-5. These data indicate that there is a significant increase in standard deviation for the 80,000 dwt tanker which occurs along most of the channel.

In Leg 1, both ship means are similar and close to the channel centerline, however, the standard deviation for the 80,000 dwt vessel is more than double that for the 30,000 dwt vessel. In the Ship Variables report it was stated that this increase in crosstrack deviation is attributed to maneuverability differences of the vessels.

In the turn maneuver, the pilots initiated the turn later with the 80,000 than with the 30,000 dwt tanker. The 80,000 dwt ship, while drifting left as it approaches the turn, has less crosstrack velocity between Data Lines 1 and 0 so the pilot must complete most of its turn after it passes the turn apex. This late turn results in an overshoot of the Leg 2 centerline and the significant difference in mean track lines.



SV5: 30,000 DWT SHIP MIDSHIP WHEELHOUSE



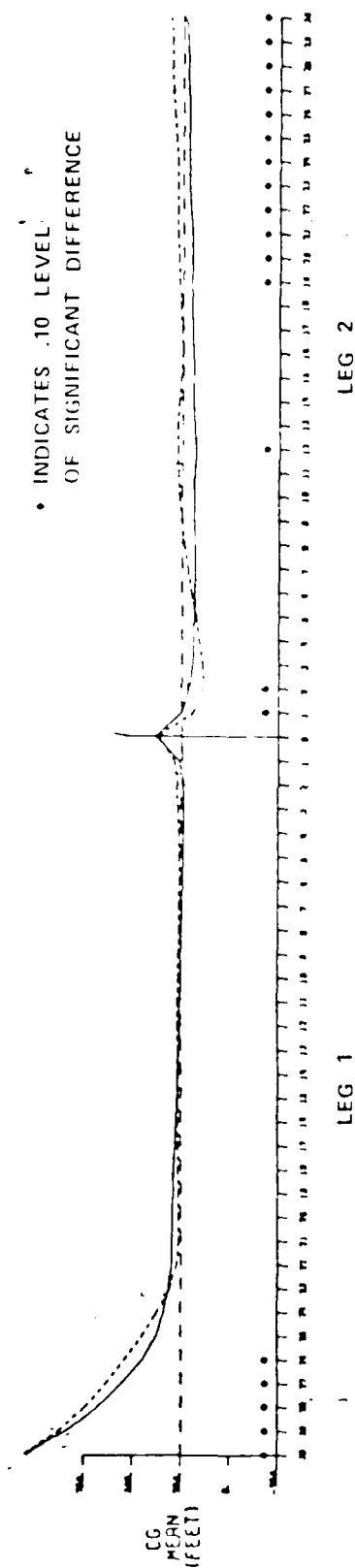
SV7: 80,000 DWT SHIP WITH AFT WHEELHOUSE

Figure C-4. Effect of Ship Size and High Buoy Density

EFFECT OF SHIP SIZE (HIGH BUOY DENSITY)

— 30,000 DWT TANKER
 - - - 80,000 DWT TANKER

• INDICATES .10 LEVEL
 OF SIGNIFICANT DIFFERENCE



♦ INDICATES .10 LEVEL
 OF SIGNIFICANT DIFFERENCE

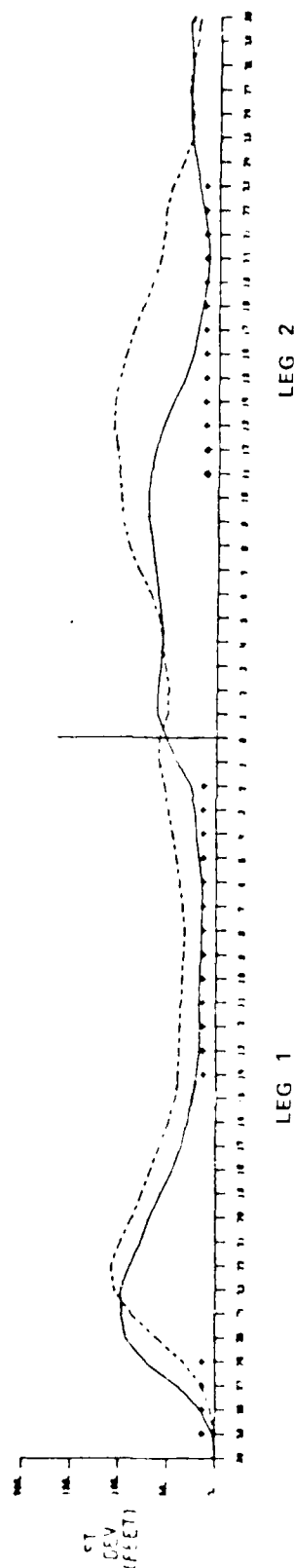


Figure C-5. Cross-track Mean and Standard Deviation of Piloting Performance, 30,000 vs. 80,000 dwt Tanker, 6 kts, High Buoy Density

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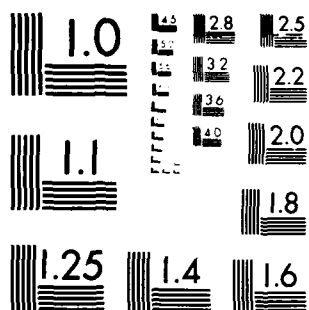
AIDS TO NAVIGATION SRA SUPPLEMENTAL EXPERIMENT
PRINCIPAL FINDINGS: PERFOR. (U) ECLECTECH ASSOCIATES
INC NORTH STONINGTON CT K L MARINO ET AL. SEP 84
EA-B3-U-166 USCG-D-03-84 DOT-CG-835285-A F/G 17/7

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

In recovering from the turn early in Leg 2, the mean track is better for the 80,000 than the 30,000 dwt vessel. The better performance is partially due to the "sail effect" of the larger ship. The mean for the 80,000 is to the left of the centerline which indicates the bow is pointed in the direction of the wind. However, there is an increase in the crosstrack standard deviation for the 80,000 dwt vessel which may be due to difficulty with ship maneuverability and to attempts by the pilots to reach the centerline position having overshoot the turn. Comparison of the standard deviations between vessels indicates the 30,000 dwt vessel is brought under consistent control in Leg 2 within 1-1/4 nm of the turn (Line 15) while the 80,000 dwt vessel required almost 2 nm (Line 25) to achieve consistent control.

In the trackkeeping region of Leg 2 (between Data Lines 18 to 30), the difference between the means remains approximately equal. A possible explanation from the Ship Variables report is that there is a region of the channel considered to be the "center" and it lies approximately +60 feet from either side of the centerline. In summary, given all of the above differences, the major contributing factor to differences in piloting performance appears to be ship maneuverability.

C.4 SUMMARY

From the previous analysis, it is concluded that the variable of ship size has a larger effect on piloted performance than the variable of buoy arrangement on piloted performance. Overall performance was best with the 30,000 dwt ship, followed closely by the 52,000, and worse with the 80,000 dwt ship regardless of buoy arrangement as is apparent by reviewing Figures C-3 and C-4. The effect of ship size is most pronounced in the turn pullout since environmental crosstrack forces (such as wind and current), the ship's advance, and transfer from the original course to the new course must be compensated for by the pilot. Figure C-6 shows the pilot groups mean and standard deviation at the turn pullout. In a low buoy density channel, it is apparent when comparing both the mean and the standard deviation of each ship that performance is best with the 30,000, followed closely by the 52,000 and dramatically worse with the 80,000 dwt ship. In a high buoy density channel, pilot performance improves with each ship, but the 80,000 dwt ship still results in significantly poorer performance than 30,000 dwt ship.

In summary, while aids to navigation have less effect than ship size, high buoy density is more accommodating to ship size than low buoy density. This means that with high density buoys, pilots have more position fixing information so they are more confident about ship's position. With the 30,000 dwt ship, performance can be improved from adequate to precise, with additional buoys. This may result in a dispersion of tracks, but this is due to different piloting strategies rather than inaccuracies. The 80,000 dwt vessel needs a higher density of buoys, merely for adequate performance in entering a channel, exiting a turn, or trackkeeping with crosswind or crosscurrent.

21

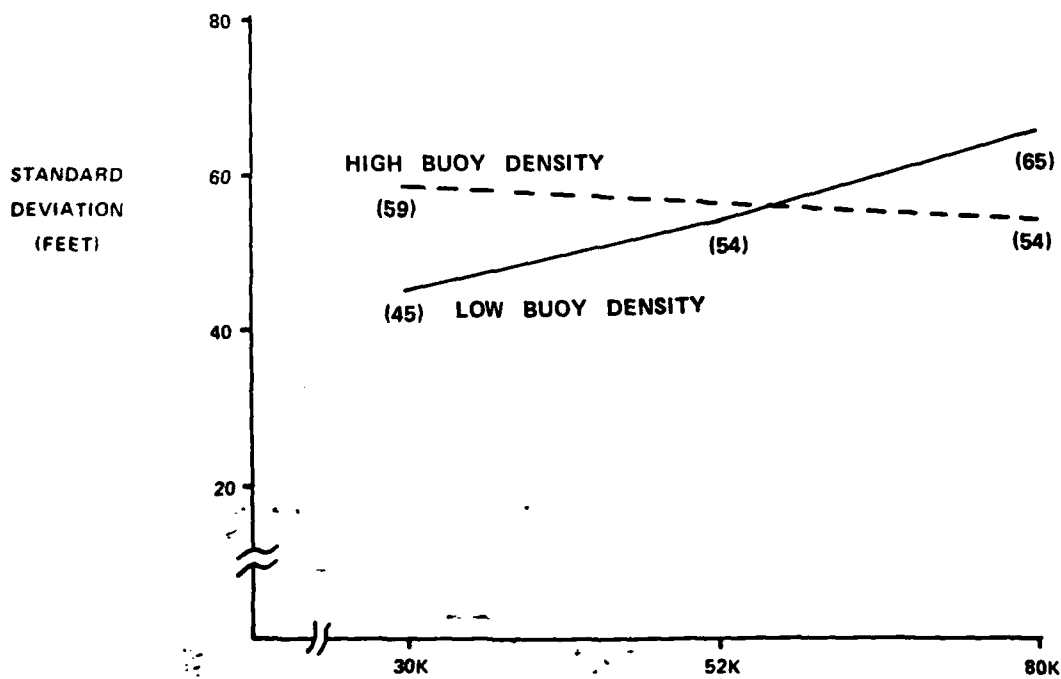
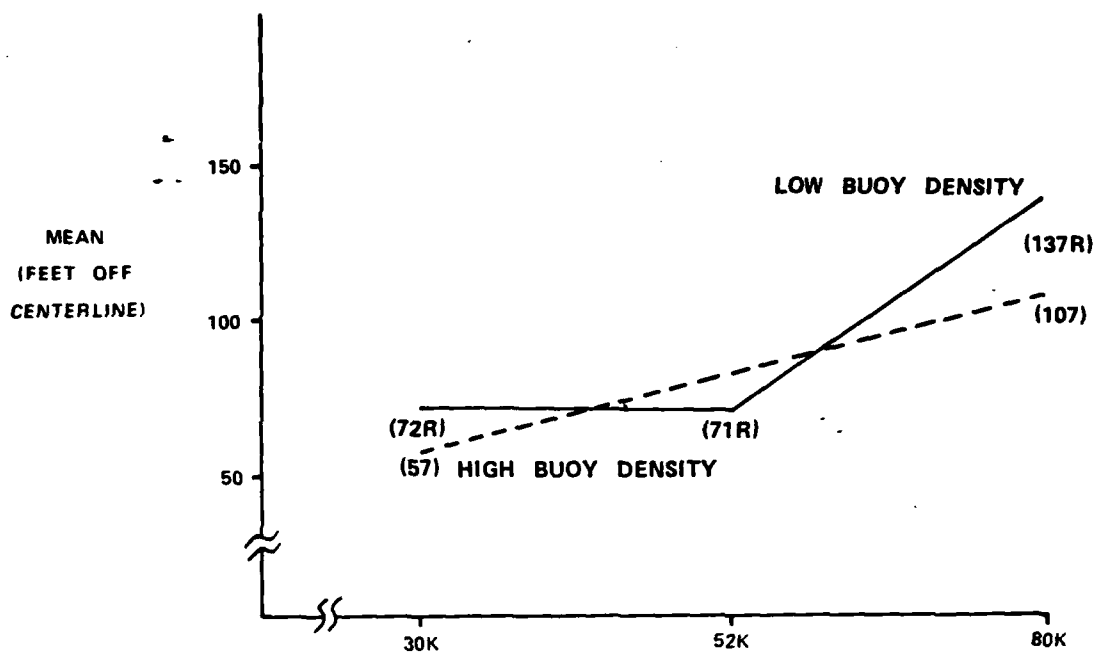


Figure C-6. Performance in Turn Pullout Ship Size Comparison

Appendix D
PILOTED PERFORMANCE AS A FUNCTION OF SHIP SPEED

D.1 SHIP SPEED AND SHIP SIZE IN A LOW BUOY DENSITY CHANNEL

The 30,000, 52,000, and 80,000 dwt ships were run at 6 and 10 knots to determine the effect of ship speed on piloted performance when transiting through a 500-foot channel marked by low buoy density. The two scenarios using the 52,000 dwt vessel were run in the SRA Supplemental Experiment. The scenarios using the 30,000 and 80,000 dwt vessels were run in the Ship Variables Experiment. The constant conditions are identified by Table D-1.

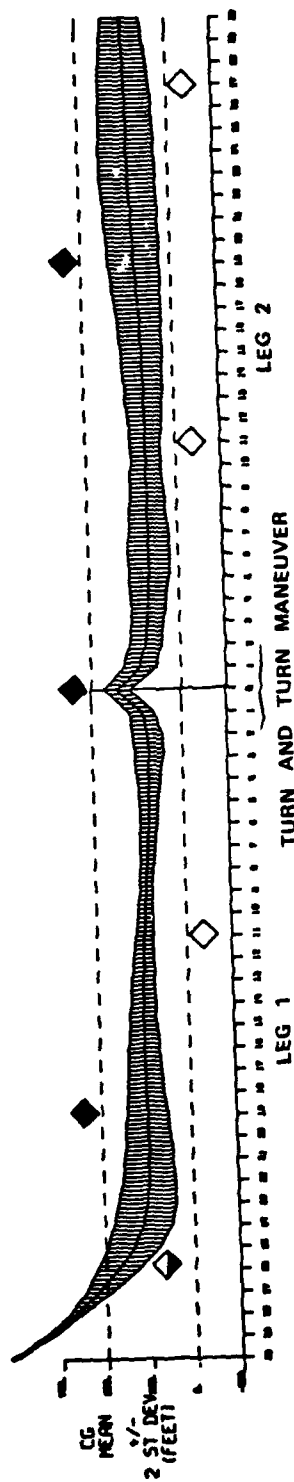
TABLE D-1. CONSTANT CONDITIONS FOR SHIP SPEED COMPARISON IN LOW BUOY DENSITY

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Channel dimensions: | <ul style="list-style-type: none">• 500-foot width• 1-foot underkeel clearance• 35-degree noncutoff turn |
| 2. Environmental effects: | <ul style="list-style-type: none">• following wind and current changing to port quarter• daytime• 1-1/2 nm visibility |
| 3. Channel markings: | <ul style="list-style-type: none">• staggered buoys spaced at 1-1/4 nm intervals along one side• 1 buoy marking the turn |

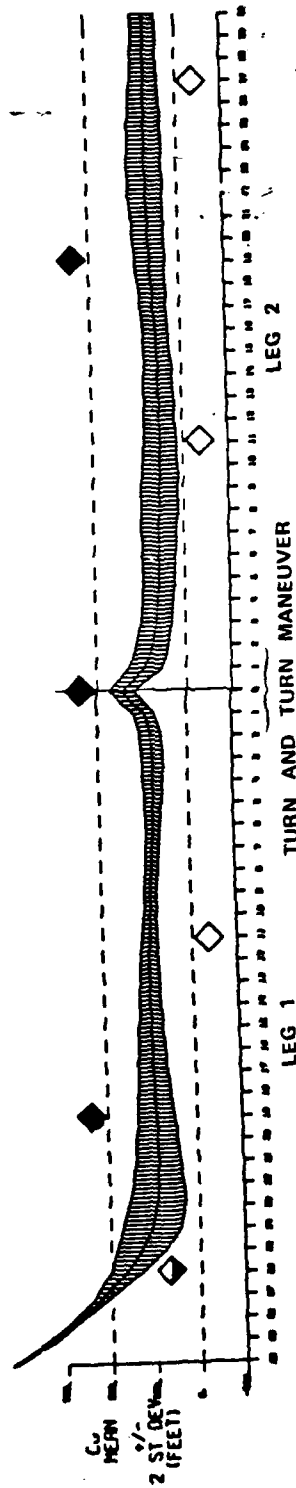
The low buoy density arrangement was selected in the Ship Variables Experiment to represent the "worst" realistic case for aids to navigation configurations. The 52,000 dwt ship was run in this experiment to fill the gap between the 30,000 and 80,000 dwt vessels run in the Ship Variables experiment. In the Ship Variables report²⁸, it was determined that increased speed, coupled with larger more difficult ships, did not necessarily improve performance as expected, in fact, it degraded performance particularly for the 80,000 dwt vessel. When a channel is marked by a low buoy density where pilots are less certain of their ship's position, a higher ship speed resulted in poorer performance. Pilots waited longer before beginning the turn maneuver so some ship tracks, particularly those of the 80,000 dwt ship, exceeding the channel edge.

Piloted performance with the 30,000 dwt tanker at both 6 and 10 knots is shown in Figures D-1 and D-2. The plots indicate that pilots successfully navigated the 30,000 dwt vessel in the low buoy density channel. The data are similar in Leg 1, the turn, and Leg 2 with no statistical differences between data lines. The data in Leg 2, however, warrant further discussion. It is observable that the lateral set from right to left in Leg 2 (Data Lines 16 to 26) is reduced by increased ship's speed. At the high ship speed the rudder is more effective in checking the wind-induced turning

²⁸W.R. Bertsche, D.A. Atkins, and M.W. Smith, op. cit.



SV2: 30,000 DWT VESSEL TRANSITING AT 6 KNOTS



SV3: 30,000 DWT VESSEL TRANSITING AT 10 KNOTS

1 DATA LINE = 475 FEET

Figure D-1. Effect of Ship Speed on 30,000 DWT Vessel, Low Buoy Density

EFFECT OF SPEED 30,000 DWT

— 6 KNOTS

- - - 10 KNOTS

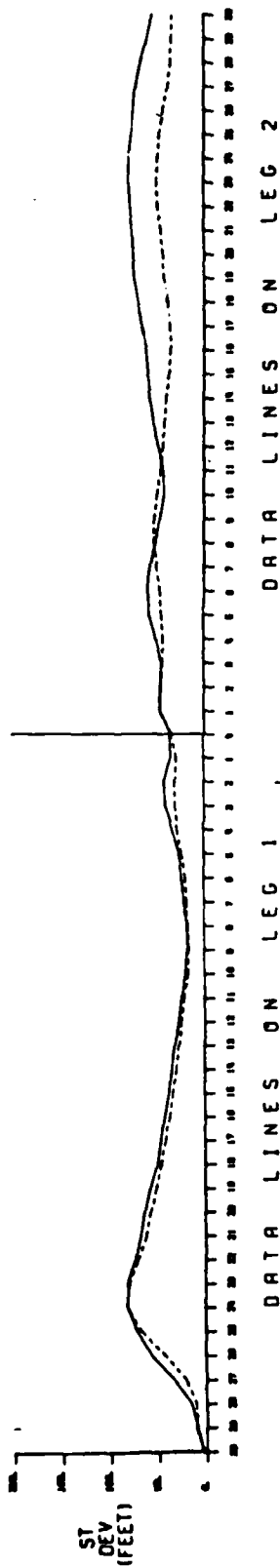
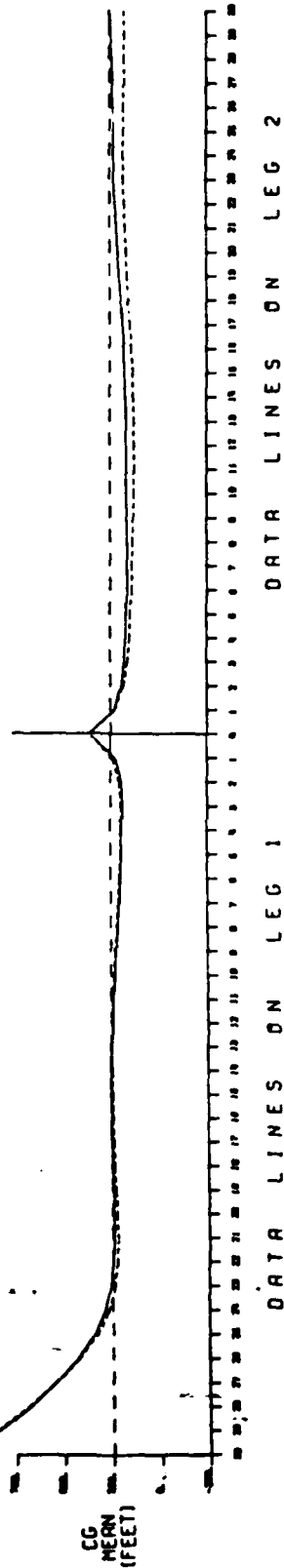


Figure 18'. Crosstrack Mean and Standard Deviation of the Piloting Performance of a 30,000 DWT Vessel at 6 and 10 Kts, Low Buoy Density

moment and the ship transits the leg much faster. The net effect appears to be a mean course at higher speed which more closely parallels the channel centerline. Increased speed does not reduce the width of the perceived "center" of the channel since a 75-foot bias to the right of the centerline remains. The reduced standard deviation in Leg 2, while not statistically significant, indicates that higher speed may aid pilots in achieving more consistent trackkeeping performance when transiting with wind and current and the 30,000 dwt ship.

Piloted performance with the 52,000 dwt tanker at both 6 and 10 knots is shown in Figure D-3 and Figure D-4 compares the effect of ship speed with the 52,000 dwt tanker. Overall, ship tracks were better when the ship transit speed was higher, particularly when maneuvering or recovering from a maneuver. The areas of statistical significance occur at Data Lines 9 and 8 in finding the centerline in Leg 1 with the mean of the 52,000 dwt vessel at 10 knots steadying up on Leg 1 earlier and closer to the centerline than when transiting at 6 knots. At 10 knots, the vessel steadied up within 20 feet of the centerline. At 6 knots, the ship track is offset approximately 50 feet to the right of the centerline. At approximately .06 nm past the turn, there is a statistical difference in the standard deviation of the ship tracks. At 10 knots, the standard deviation of ship tracks is less than 50 feet. This shows that piloting strategies are similar and pilots as a group are not experiencing difficulty compensating for the wind and current. At 6 knots, the dispersion of ship tracks is wide between Data Lines 7 and 12. The ship tracks fall within a much wider envelope with a standard deviation of 90 feet. Since in this region the ship means are similar, it shows that some pilots are having difficulty compensating for the set of the current. At a 6 knot ship speed, the environmental conditions have a greater impact than it has when the ship transits at 10 knots. Trackkeeping in Leg 2 results in statistical differences between the mean tracks. When transiting at 10 knots the pilots are better able to compensate for the lateral set due to wind and current since the mean track tends to be straighter and the standard deviation is more constant. At 6 knots the mean track is closer to the centerline, but it never steadies out. At the slower speed, the pilots tend to give more commands and to buoy hop. This verifies the pilots' belief that the ship is more responsive at faster speeds.

Piloted performance with the 80,000 dwt tanker at both 6 and 10 knots is shown in Figure D-5. Pilots had difficulty with the 80,000 dwt in entering the channel and in completing the turn. This is apparent since some of the tracks skirted the channel edge. Since the tracks shown by the figure are at the ship's center of gravity, the tracks actually extend further out if adjusted for the width of the beam. Figure D-6 compares the mean and standard deviation for each speed. Some improvement in performance is evident in Leg 1 since the standard deviation for 10 knots is less than that for 6 knots. Here, the higher speed aids in recovering from the turn into the channel. The improvement, however, is localized and may indicate differences in strategy and in initial course. Turning performance shows a high crosstrack standard deviation exiting the turn at 6 knots. While not statistically different, the data indicate that turning at 10 knots may be somewhat less consistent than at 6 knots. This degradation, however, may be relatively small since the increase is not statistically supportable.

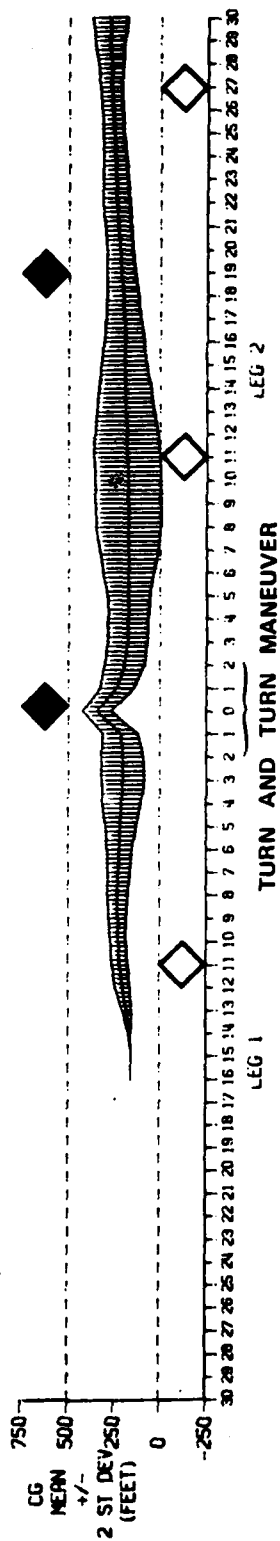
Trackkeeping performance shows statistically significant differences occur in both the mean tracks and the standard deviations. The mean track for 10 knots indicates less lateral set similar to the 30,000 dwt tanker at 10 knots. Again, this is likely due to the ability to counter the wind with smaller rudder angles and the reduced time the ship requires to transit Leg 2. The differences in crosstrack standard deviations in Leg 2 appear to occur as a result of oscillatory behaviors which are out of phase. The source of this oscillatory behavior was not determined in the Ship Variables Report.²⁹ Since the buoy spacing is 1.25 nm, it was hypothesized in the Ship Variables Report that the oscillations occur as a function of buoyhopping or zig-zagging in a staggered channel. Similar behavior was previously noted with staggered buoy configurations in the Channel Width Experiment³⁰ and in the One Side Experiment³¹ where pilots favored the channel boundary that was marked with the navigational aid.

In summary, the 30,000 and 52,000 dwt ships performed satisfactorily at both 6 and 10 knots in a channel marked by a low buoy density. Performance with the 80,000 dwt ship was poor when compared with the smaller ships. The difficulty with the 80,000 dwt ship lies in the inability of all the pilots to recover from a sharp maneuver such as entering a channel by a sea buoy or making a 35-degree turn. The problem is complicated by the lack of navigation aids to mark the channel boundaries of critical areas where some tracks exceed channel limits. The next section evaluates performance with the 80,000 in a well-marked channel with a high density of buoys.

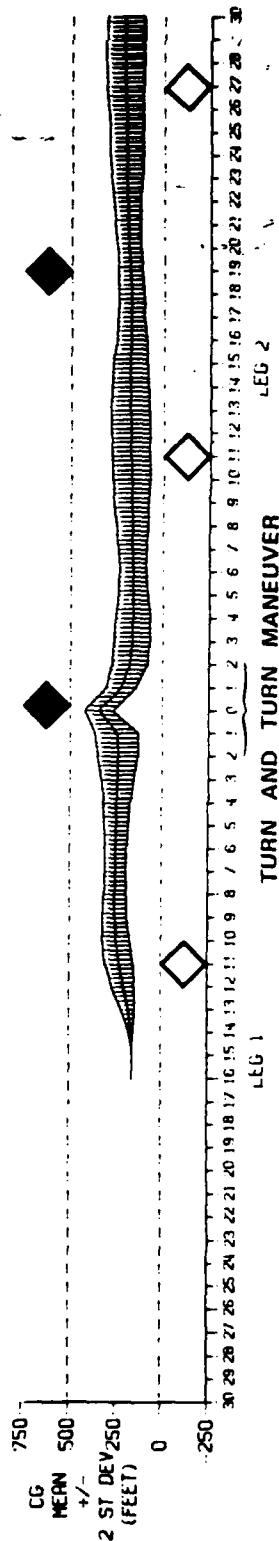
²⁹Ibid.

³⁰M.W. Smith and W.R. Bertsche, op. cit.

³¹K.L. Marino, M.W. Smith, and W.R. Bertsche



SRA 11: 52,000 DWT VESSEL TRANSITING AT 6 KNOTS



SRA 12: 52,000 DWT VESSEL TRANSITING AT 10 KNOTS

1 DATA LINE = 475 FT

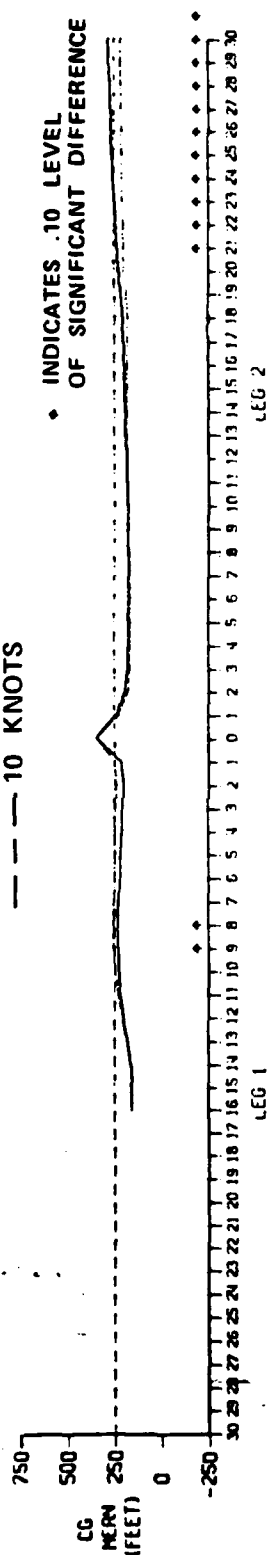
Figure D-3. Effect of Ship Speed on 52,000 DWT Vessel, Low Buoy Density

EFFECT OF SPEED 52,000 DWT

— 6 KNOTS

- - - 10 KNOTS

• INDICATES .10 LEVEL
OF SIGNIFICANT DIFFERENCE



• INDICATES .10 LEVEL
OF SIGNIFICANT DIFFERENCE

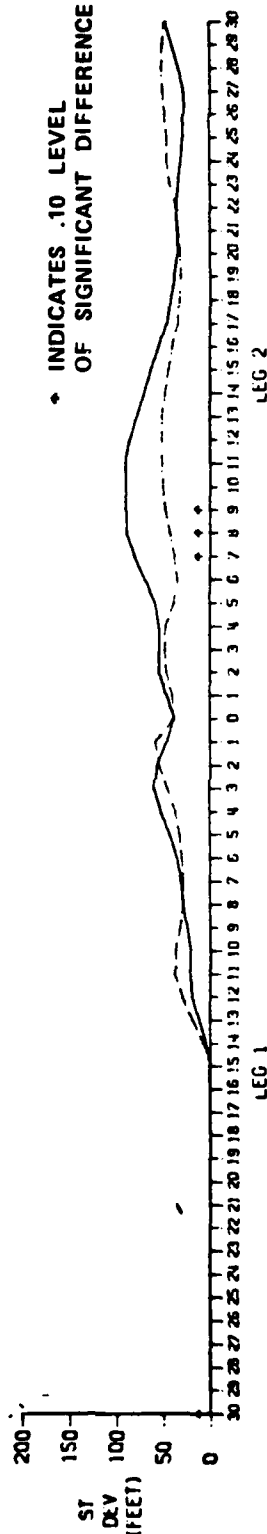
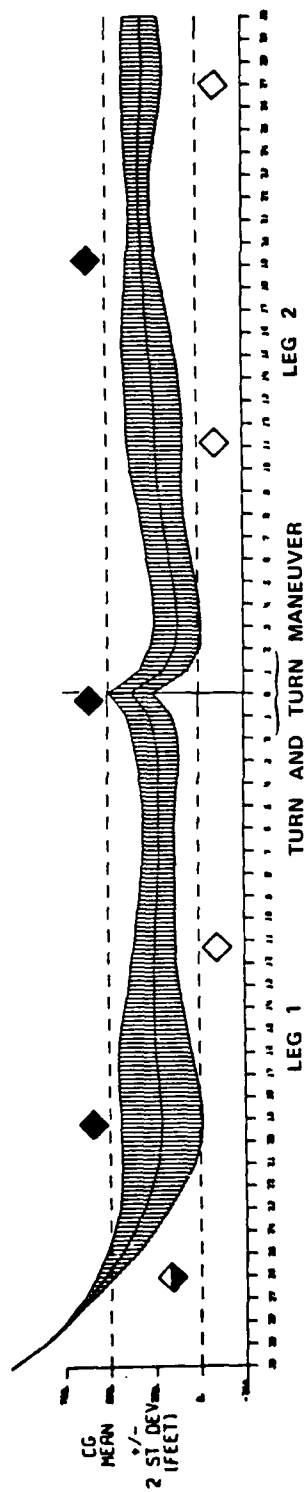
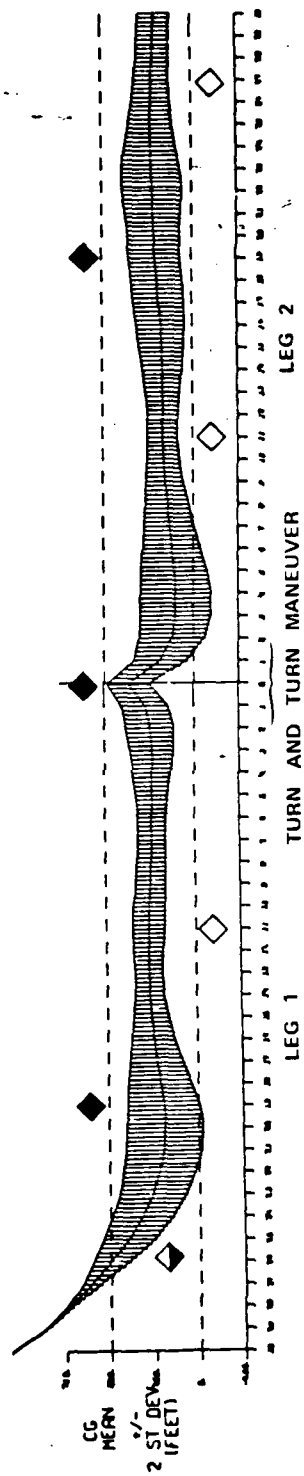


Figure D-4. Crosstrack Mean and Standard Deviation of the Piloting Performance of a 52,000 dwt Vessel at 6 and 10 Knots, Low Buoy Density



SV6: 80,000 DWT VESSEL TRANSITING AT 6 KNOTS



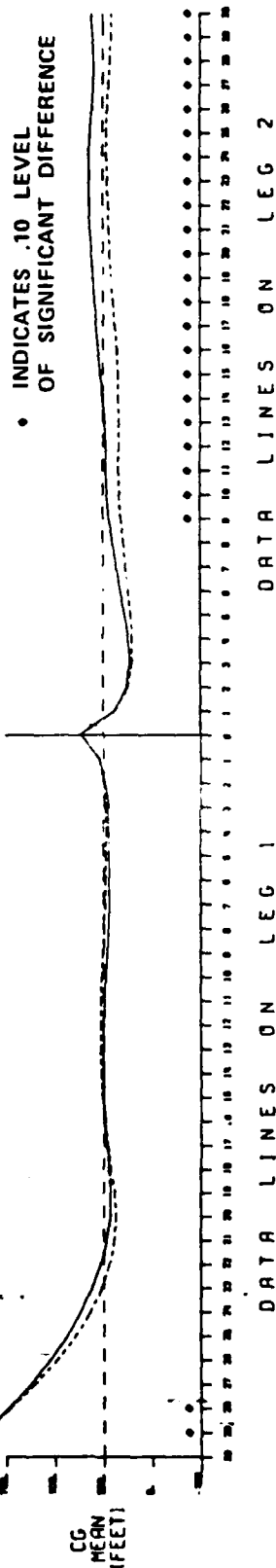
SV8: 80,000 DWT VESSEL TRANSITING AT 10 KNOTS

1 DATA LINE = 475 FEET

Figure D-5. Effect of Ship Speed on 80,000 DWT Vessel, Low Buoy Density

EFFECT OF SPEED 80,000 DWT

— 6 KNOTS
 --- 10 KNOTS



D-9

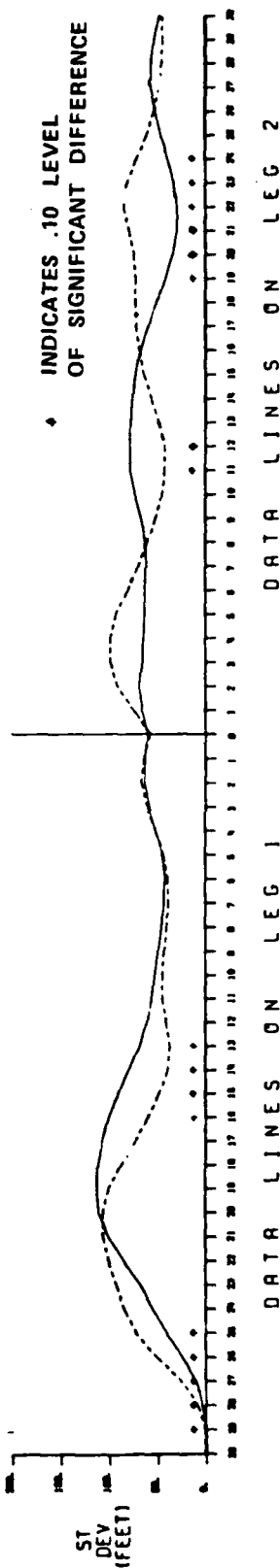


Figure D-6. Crosstrack Mean and Standard Deviation for the Piloting Performance of an 80,000 DWT Tanker at 6 and 10 Kts, Low Buoy Density

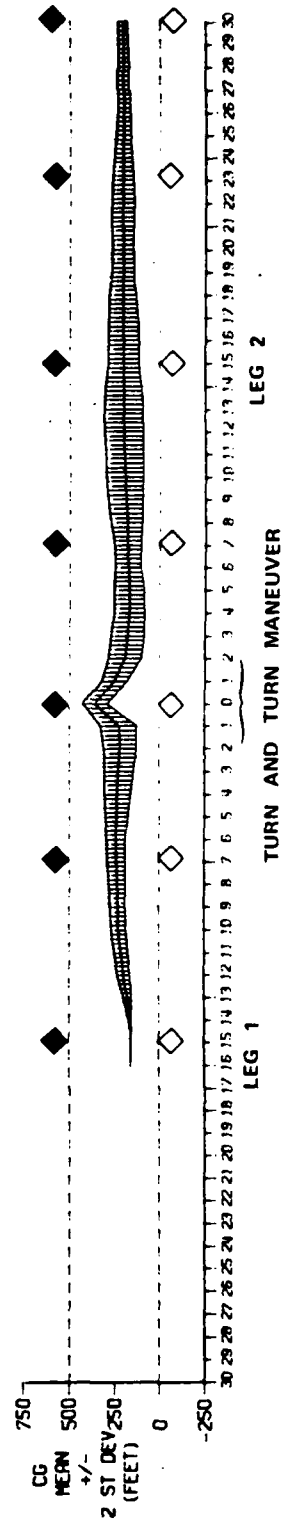
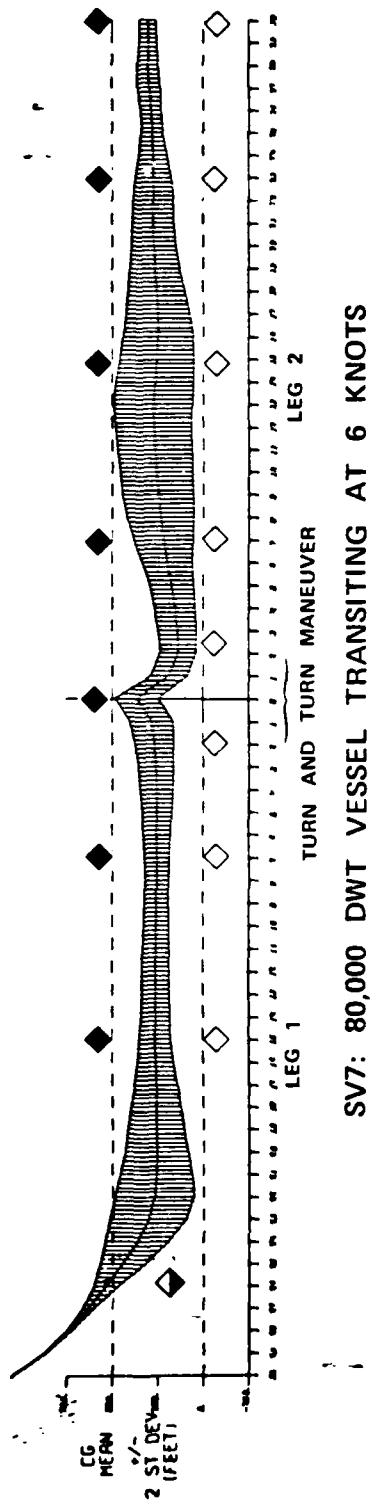
D.2 SHIP SPEED AND THE 80,000 DWT SHIP IN A HIGH BUOY DENSITY CHANNEL

The 80,000 dwt ship was run at 6 and at 10 knots to determine the effect of ship speed on piloted performance in a channel marked by a high buoy density. Data was collected with the high buoy density arrangements to represent optimal conditions where pilots often navigate at higher speeds. Data with the 80,000 dwt ship transiting at 6 knots was taken from the Ship Variables Experiment, and data with the 80,000 dwt ship transiting at 10 knots was collected in the SRA Supplemental Experiment. The 80,000 dwt ship was selected to be evaluated because it was expected that the bigger ship was more likely to show the effects of speed under high buoy density conditions. The constant conditions are identified by Table D-2.

TABLE D-2. CONSTANT CONDITIONS FOR SHIP SPEED COMPARISON
IN A HIGH BUOY DENSITY

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Channel dimensions: | <ul style="list-style-type: none">• 500-foot width• 1-foot underkeel clearance• 35-degree noncutoff turn |
| 2. Ship: | <ul style="list-style-type: none">• 80,000 dwt ship• rear wheelhouse |
| 3. Environmental effects: | <ul style="list-style-type: none">• following wind and current changing to port quarter• daytime• 1-1/2 nm visibility |
| 4. Channel markings: | <ul style="list-style-type: none">• gated buoys spaced at 5/8 nm marking the straight legs• 3 buoys marking the turn |

Piloted performance with the 80,000 dwt vessel at both 6 and 10 knots is shown by Figure D-7. Performance is better at the higher speed. In Leg 1 (between Data Lines 11 and 4) the mean tracks are within 20 feet of the centerline. The wider standard deviation of SV 7 is due to the effect of the sea buoy rather than the 6 knot speed. Differences in performance become apparent in the turn maneuver. The pilots set up for the turn earlier about Data Line 4 and make the turn more gradually at 10 knots. At 6 knots, the pilots initiate the turn approximately 750 feet closer to the turn. At 6 knots the ship tracks are set by the current further to the right, and the pilots have difficulty recovering from the turn and compensating for the current. Throughout most of Leg 2, piloted performance is worse at 6 knots. This could have several causes: (1) the sea buoy in SV 7 results in an unfair bias since the ship starts out 2400 feet outside the channel on a different heading rather than starting as in SRA 5 inside the channel with a 100-foot offset from the centerline, (2) the poorer ship position of SV 7, as a result of the turn, caused more of a problem in recovering from the turn than SRA 5, and (3) the slower ship speed results in the impact of the wind and current being stronger on SV 7.



1 DATA LINE = 475 FEET

Figure D-7. Effect of Ship Speed on 80,000 DWT Vessel, High Buoy Density

In the presimulation report³² it was hypothesized that since a high buoy density marks the channel ship speed would have a minimal effect on piloted performance regardless of ship size (see Appendix I). This was expected because the buoy arrangement provides the pilot excellent position fixing information. This hypothesis is not supported because there are significant differences in pilot performance at different transit speeds in the turn maneuver, turn recovery, and trackkeeping in Leg 2. When pilots have "good" information to gauge ship position, performance is better at higher speed; pilots guess less, make better judgements, and their tracks are smoother and more steady. At slower speeds the ship is more susceptible to environmental effects such as wind and current so the pilot must constantly "check" the ship to reduce the setting effect of current.

Earlier, in the Ship Variables Report,³³ it was hypothesized that higher speeds would improve performance. However, the data run in that experiment did not result in improved performance with higher speed because the scenarios were run with low buoy density arrangements. New data collected in this experiment, indicate that piloted controllability improves with speed when given a high buoy density arrangement. With high-density buoy arrangements, the speed advantage is most apparent in the turn pullout and recovery regions. The advantage of speed decreases when trackkeeping because the pilots can easily keep a ship on track.

D.3 SUMMARY

In a low buoy density, the 30,000 and 52,000 dwt ships were piloted satisfactorily at both 6 and 10 knots. Performance with the 80,000 dwt ship was poor when compared with the smaller ships. The difficulty with the 80,000 dwt ship lies in the inability of all the pilots to recover from a sharp maneuver such as entering a channel by a sea buoy or making a 35-degree turn. The problem is complicated by the lack of navigation aids to mark the channel boundaries of critical areas when some tracks exceed channel limits.

In a high buoy density where pilots have "good" information to gauge ship position, performance is better at a higher speed. Pilots make better judgements so their tracks are smoother and more steady. At slower speeds the ship is more susceptible to environmental effects so the pilots must constantly "check" the ship to reduce the effect of such factors as wind and current.

³²K.L. Marino and M.W. Smith, op. cit.

³³W.R. Bertsche, D.A. Atkins, and M.W. Smith, op. cit.

Appendix E
PILOTED PERFORMANCE AS A FUNCTION OF CHANNEL WIDTH

E.1 INTRODUCTION

This section evaluates the interaction between channel width and ship size. Table E-1 identifies data available to evaluate this interaction. The numbers on the table in parentheses identify buoy spacing. Most data pertains to the 30,000 dwt ship in the 500-foot channel. Scenario 6 from this experiment consists of the 80,000 dwt ship transiting in an 800-foot channel and was included for further analysis of the channel width and ship size interaction.

TABLE E-1. CHANNEL WIDTH CONDITIONS

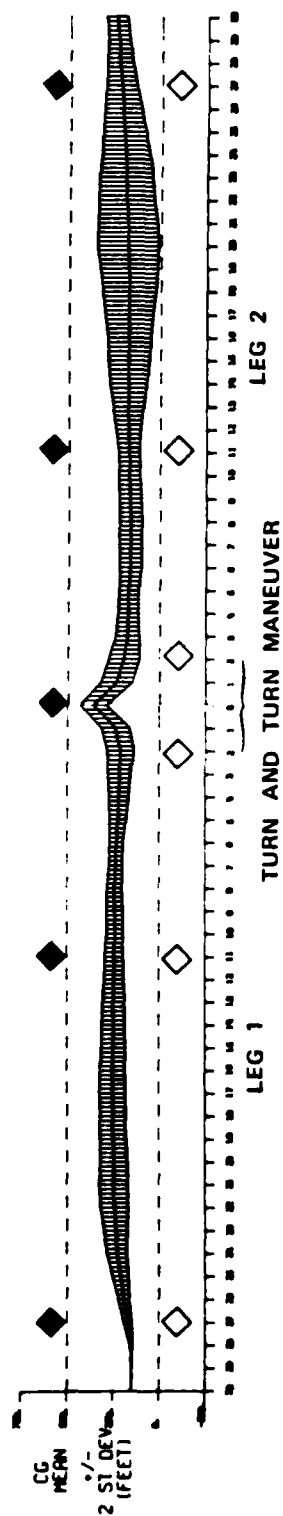
| Ship Size (dwt) | Channel Width | |
|-----------------|---------------|---------------|
| | 500 feet | 800 feet |
| 30,000 | CW 2 | CW 6 (1-1/4) |
| | SV 5 (5/8) | |
| | OS 1 | |
| | CW 4 (1-1/4) | |
| 80,000 | SV 7 (5/8) | SRA 6 (1-1/4) |

E.2 CHANNEL WIDTH AND THE 30,000 DWT SHIP

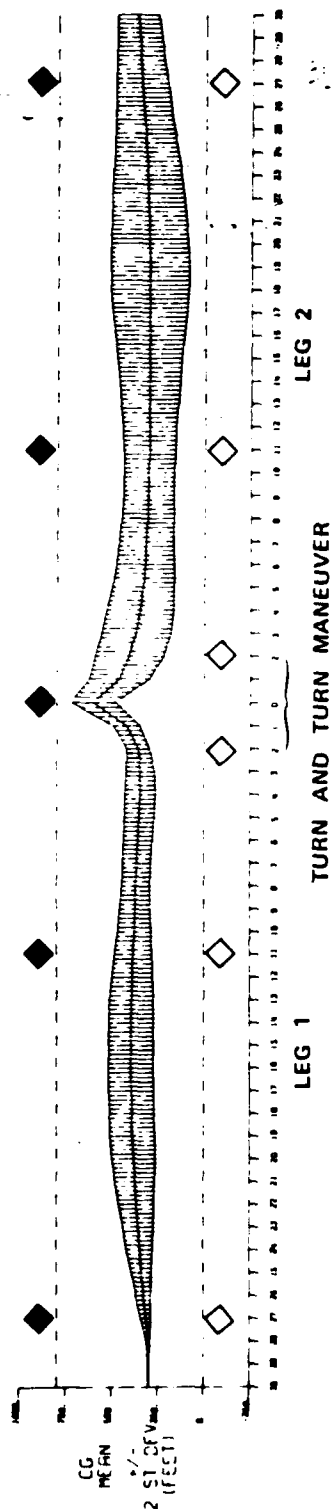
The 30,000 dwt ship was run frequently in previous experiments. Scenarios CW 4 and CW 6 were selected to evaluate the effect of channel width on the 30,000 dwt ship because they are from the same experiment and the channels are marked identically. The constant conditions are listed in Table E-2.

Piloted performance with the 30,000 dwt ship in the 500-foot and 800 foot channel is shown by Figures E-1 and E-2. Overall, performance is more precise with the 30,000 dwt ship in the 500-foot channel. In the 800-foot channel, pilots are either more lax in staying on the centerline since there is a larger "margin of safety" or they have perceptual difficulties identifying the centerline. Possibly, the wider channel results in less accurate estimates of ship position, especially with the small ship bow to gauge the distance off the buoys.

In Leg 1, piloted performance was satisfactory with the 30,000 dwt ship in both channels, however, performance was superior in the 500-foot channel. The standard deviation in the 800-foot channel was significantly higher between Data Lines 13 through 6. When trackkeeping with a following wind and current in the wide channel the tracks were more widely spread and the "centerline region" was not as accurately perceived as it was in the 500-foot channel.



CW4: 30K IN 500 FOOT CHANNEL WITH GATES AT 1 1/4 NM



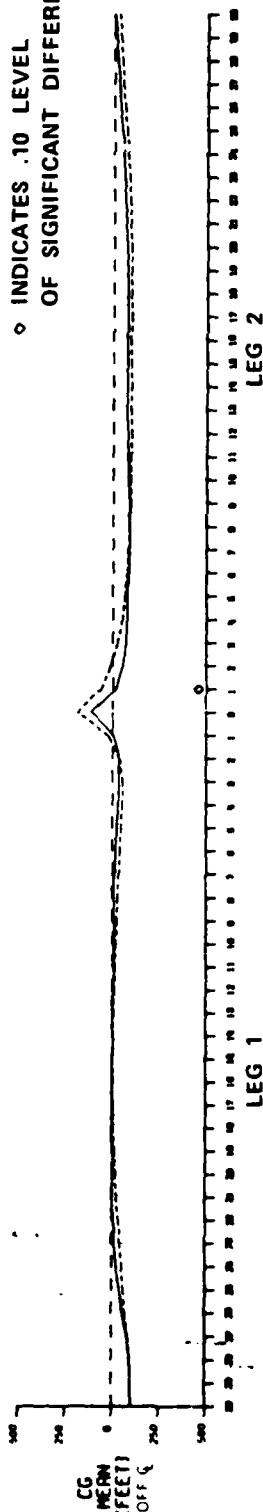
CW6: 30K IN 800 FOOT CHANNEL WITH GATES AT 1 1/4 NM

Figure E-1. Performance Differences with 30,000 in a 500-Foot and an 800-Foot Channel,
1-1/4 nm Gates and 3-Buoy Turn

SCENARIO 4 VS 6 GATED - 1 1/4 SPAC - CENTER - 500 FT VS 800 FT

— 500 FT CHANNEL (CW4)
 - - - 800 FT CHANNEL (CW6)

o INDICATES .10 LEVEL
 OF SIGNIFICANT DIFFERENCE



E-3

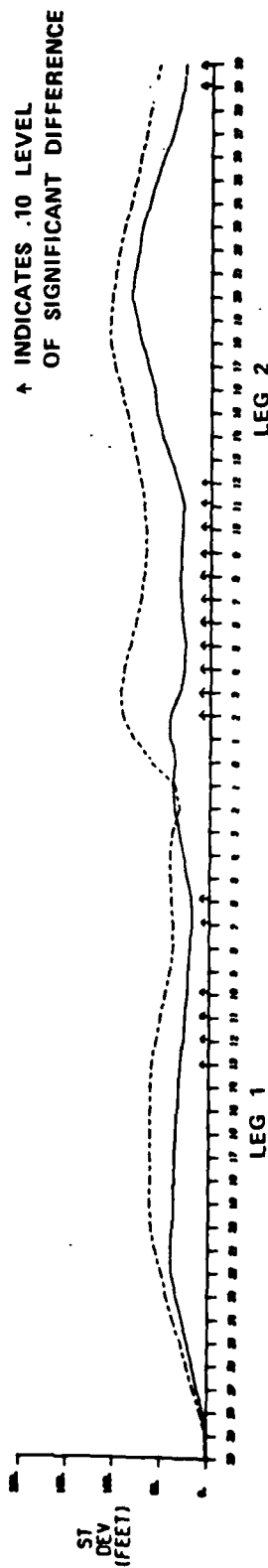


Figure E-2. Crosstrack Mean and Standard Deviation of 30,000 dwt Ship in 500-Foot Versus an 800-Foot Channel

TABLE E-2. CONSTANT CONDITIONS FOR CHANNEL WIDTH
AND THE 30,000 DWT SHIP COMPARISON

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Ship: | <ul style="list-style-type: none"> • 30,000 dwt tanker • midship wheelhouse • 6-knot speed • 1-foot underkeel clearance |
| 2. Channel markings: | <ul style="list-style-type: none"> • gated buoys spaced at 1-1/4 nm intervals • 3-buoy turn |
| 3. Environmental effects: | <ul style="list-style-type: none"> • following wind and current changing to port quarter • 1-1/2 nm visibility |

In the turn, pilots maneuvered sharply, but concisely, in the 500-foot channel. In the pullout, although the mean was 72 feet off the centerline, the standard deviation was only 32 feet. It was made wider and more gradual in the 800-foot channel. The turn was initiated left of centerline, and at the turn pullout the ship was 28 feet right of centerline with a 94-foot standard deviation. The standard deviation was significantly higher than the 500-foot channel due to variation in pilot strategy. Some pilots made the turn identically to that made in the 500-foot channel by keeping the same distance off the turn buoy while others made the turn centerline to centerline.

In Leg 2, piloted performance was better in the 500-foot channel. The dispersion of the tracks between Data Lines 2 through 12 in the 800-foot channel is approximately double that of the 500-foot channel. There are several reasons for this: (1) pilots varied turn strategies so after the turn pullout the ship's crosstrack position was dispersed, (2) pilots felt safe in the channel and allowed themselves less precision, and (3) pilots have a perceptual problem with ship position since the midship bow presents little reference in front of them. Perceptual difficulty with a smaller bow was also found in the Ship Variables Experiment³⁴. The 30,000 dwt ship was run with two bows (a small bow and the midship bow) and performance was better with the larger bow. It can be speculated that performance would be better with the 30,000 dwt ship if it had a rear wheelhouse.

³⁴Ibid.

E.3 CHANNEL WIDTH AND THE 80,000 DWT SHIP

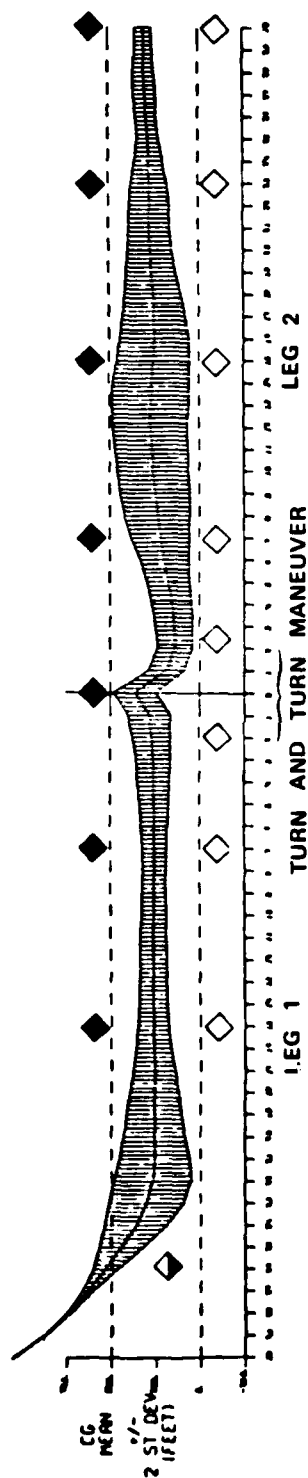
SRA 6 was compared to SV 7 to evaluate piloted performance with the 80,000 dwt ship in a 500- and an 800-foot channel. The 80,000 dwt SV 7 scenario transits in a 500-foot channel marked by short spaced (5/8 nm) gated buoys. The SRA 6 scenario transits in an 800-foot channel marked by long spaced (1-1/4 nm) gated buoys. Since by its size and its maneuverability, the 80,000 is difficult to handle, it is given an advantage in the 500-foot channel by a higher buoy density, and in the 800-foot channel the advantage is more channel. The constant conditions are identified by Table E-3.

TABLE E-3. CONSTANT CONDITIONS FOR CHANNEL WIDTH
AND THE 80,000 DWT SHIP COMPARISON

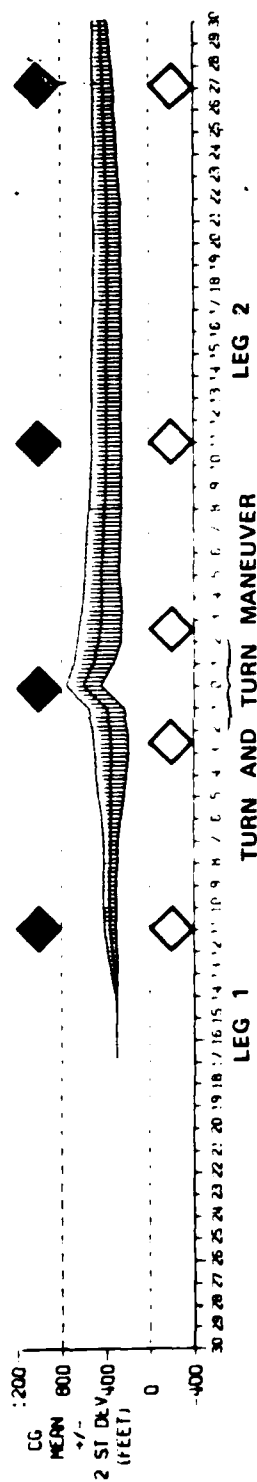
| | |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Ship: | <ul style="list-style-type: none">● 80,000 dwt tanker● aft wheelhouse● 1-foot underkeel clearance● 6-knot speed |
| 2. Channel markings: | <ul style="list-style-type: none">● gated buoys● 3 buoys marking the turn |
| 3. Environmental effects: | <ul style="list-style-type: none">● following wind and current changing to port quarter● 1-1/2 nm visibility |

Piloted performance with the 80,000 dwt ship is shown by Figure E-3. Statistical differences between scenarios are identified in Table E-4. In the 500-foot channel, the 80,000 dwt ship tracks were widely dispersed in the recovery to the channel centerline in Leg 1 and in the turn pullout and recovery in Leg 2. The ship tracks in the 500-foot channel came close to the edge in the turn pullout, but the tracks did not exceed it. In the 800-foot channel, the mean track was generally further left in the channel. Although ship tracks were sometimes widely dispersed, the ship tracks did not near the channel edge. Overall, it appears that risk for large vessels decreases as channel width increases.

Throughout Leg 1, there is a statistical difference between the means of the 80,000 in the 500-foot channel and in the 800-foot channel. This difference is due to initialization of the scenarios. In the 500-foot channel, the SV 7 scenario started approximately 2.34 nm before the turn and outside of the channel. The wide standard deviation prior to Data Line 16 is due to differing strategies to bring the ship to the centerline. The mean track is within 10 feet of the centerline from Data Line 21 until turn initiation at Data Line 3. In the 800-foot channel, SRA 6 started approximately 1.3 nm before the turn and were offset only 100 feet from centerline. However, the pilots never found the centerline and the mean track is generally about 50 feet off the centerline. This shows that when trackkeeping in a following wind and current the pilots can accurately determine their position in the high buoy density 500-foot channel.



SV7: 80K IN 500 FOOT CHANNEL WITH GATES AT 5/8 NM



SRA6: 80K IN 800 FOOT CHANNEL WITH GATES AT 1-1/4 NM

NOTE: SCALE FOR 800 FOOT CHANNEL IS SMALLER THAN THAT FOR 500 FOOT CHANNEL

Figure E-3. Performance Differences with 80,000 in a 500-Foot Channel With 5/8 nm Gates Versus 800-Foot Channel, Turns Marked with 3 Buoys

TABLE E-4. STATISTICAL DIFFERENCES IN PILOTED PERFORMANCE
WITH THE 80,000 DWT SHIP IN 500 VERSUS 800-FOOT CHANNEL

MEAN TRACKS

| Channel Width | LEG 1 | | TURN | | LEG 2 | |
|---------------|------------------------|------|------------------------|------|--------------------|------|
| | Trackkeeping Data Line | Mean | Turn Pullout Data Line | Mean | Recovery Data Line | Mean |
| 500 | 8 | 5L | 3 | 107R | 11 | 21L |
| 800 | 6 | 50R | 3 | 34L | 10 | 17R |
| | | | | | 30 | 56L |
| | | | | | 30 | 42L |

STANDARD DEVIATION

| Channel Width | LEG 1 | | TURN | | LEG 2 | |
|---------------|------------------------|------|------------------------|------|--------------------|------|
| | Trackkeeping Data Line | Mean | Turn Pullout Data Line | Mean | Recovery Data Line | Mean |
| 500 | 4 | 45 | 3 | 54 | 13 | 108 |
| 800 | 5 | 59 | 3 | 95 | 7 | 76 |
| | | | | | 30 | 22 |
| | | | | | 30 | 31 |

Arrows indicate statistical differences

However, in the 800-foot channel marked by longer-spaced gated buoys, ship position cannot be as accurately assessed with a band of indifference of about +50 feet. In the wider channel it is not as crucial to be exact because the channel is more forgiving.

When turning in the 500-foot channel, the pilots maneuver severely to get the ship through the narrow channel. They initiate the turn within 10 feet of the centerline and the mean crosses the centerline approximately 300 feet (near Data Line 1) past the turn buoy in Leg 2. At turn completion, the ship's position is right of centerline and the ship is set further to the right by the current. The pilots do not control this until Data Line 4 (approximately 1900 feet beyond the turn apex). At this point the mean track moves toward the centerline. The pilots turn more gradually in the 800 foot channel. The turn is initiated 200 feet later and the mean is offset 50 feet from the centerline. Since the ship is right at turn initiation and the channel is wide, the pilots make the turn smoother and more gradual. In the pullout the ship is to the left of the channel. The turn maneuver is completed at Data Line 3, however, the mean track does not near the centerline until Data Line 6.

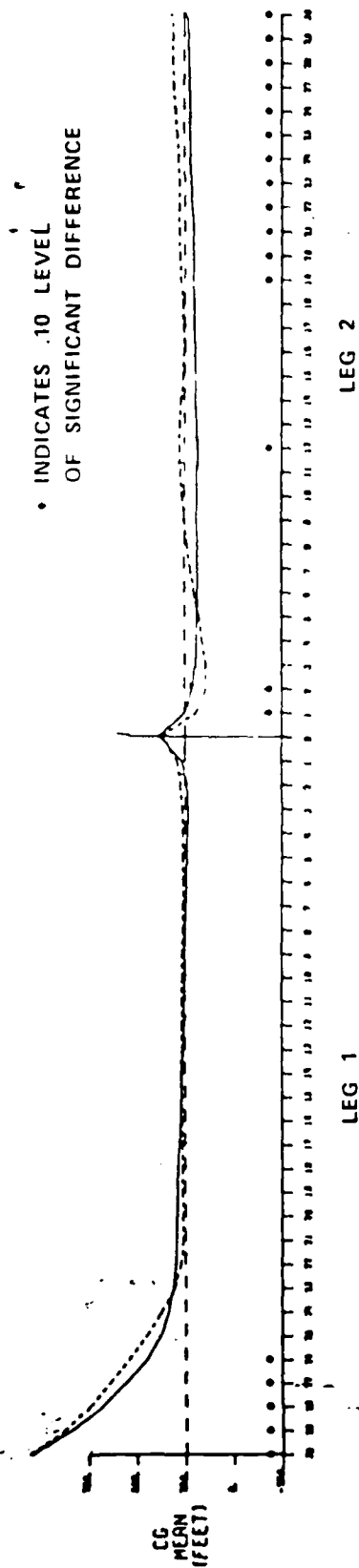
In recovering from the turn in Leg 2, there are no statistical differences between the mean and standard deviation of tracks between Data Lines 7 and 14. In both instances, the mean is within 20 feet of the centerline. However, the dispersion of tracks around the mean is worse for the 500-foot channel. This is due to the set of the current on the ship in the turn pullout. The high standard deviation of nearly 100 feet is due to differences in ship position and strategies to return to the centerline. In the 800-foot channel the standard deviation was generally about 70 feet. This better performance results from ship position in the turn pullout. Because there is more room in the inside of the channel, the pilots made the turn to left of centerline and closer to the turn buoy. They did not use as much of the outside portion of the channel so they controlled the set of the current. In the trackkeeping portion of both channels, piloted performance became more similar with a reduction in the dispersion of tracks. Therefore, the percentage of channel used decreased. In the 500-foot channel, the sail effect of the 80,000 dwt vessel is apparent since the mean track moves in the direction of the wind. It also shows signs of occurring in the 800-foot channel in the last 2000 feet of transit. Only when trackkeeping is the performance of the 80,000 dwt satisfactory in the 500-foot channel.

E.4 SHIP SIZE AND THE 500-FOOT CHANNEL

Two Ship Variables Scenarios, SV 5 and SV 7, were selected to evaluate the effect of ship size on piloted performance. Scenario SV 5 transits with a 30,000 dwt ship and Scenario SV 7 transits with an 80,000 dwt ship. These scenarios were selected because the 500-foot channels are identically marked with gated buoys spaced at 5/8 nm intervals and were run in the same experiment. Piloted performance in these scenarios has been previously discussed in Section 2 and Appendix C of this report and Section 5 of the Ship Variables report. Therefore, the differences will be summarized. The scenarios were used to evaluate the effect of ship size in a 500-foot channel marked by a high buoy density.

EFFECT OF SHIP SIZE IN 500 FOOT CHANNEL

— 30,000 DWT TANKER
 - - - 80,000 DWT TANKER



E-9

• INDICATES .10 LEVEL OF SIGNIFICANT DIFFERENCE

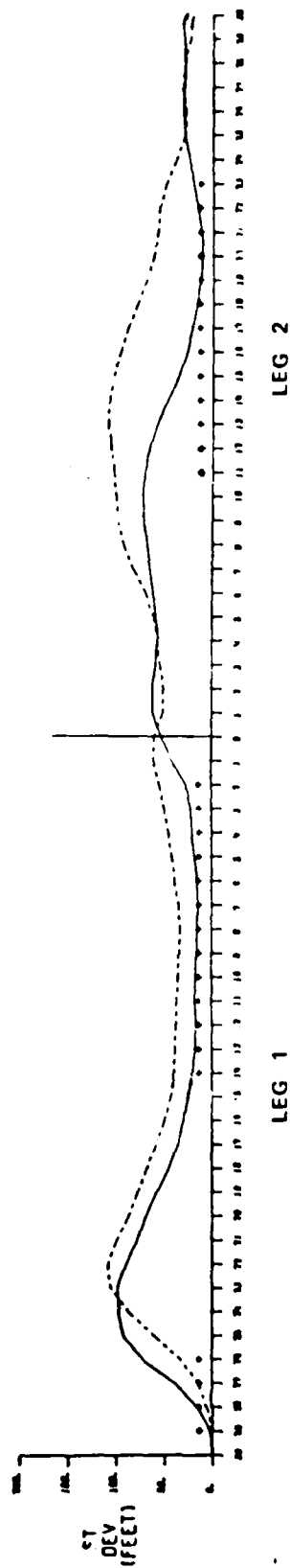


Figure E-4. Crosstrack Mean and Standard Deviation of Piloting Performance
 30,000 Versus 80,000 dwt Ship in 500-Foot Channel

The effect of ship size in the 500-foot channel is as ship size increases overall performance becomes poorer. As seen in Figure E-4 in Leg 1 the 80,000 has more than double the standard deviation than the 30,000. This is due to ship maneuverability differences. The pilots initiate the turn maneuver later with the 80,000 dwt ship which results in an overshoot of the centerline in Leg 2. In recovering from the turn the mean track of the 80,000 is better than that of the 30,000 and this is partially due to the aft bridge increasing the ship's sail effect. This explains why the 80,000 mean track is left of centerline. In comparing the standard deviation between vessels, the 30,000 dwt vessel is brought under consistent control 1-1/4 nm past the turn, while the 80,000 dwt vessel requires almost 2 nm to achieve consistent control. Again, this is due to ship maneuverability differences.

E.5 SHIP SIZE AND THE 800-FOOT CHANNEL

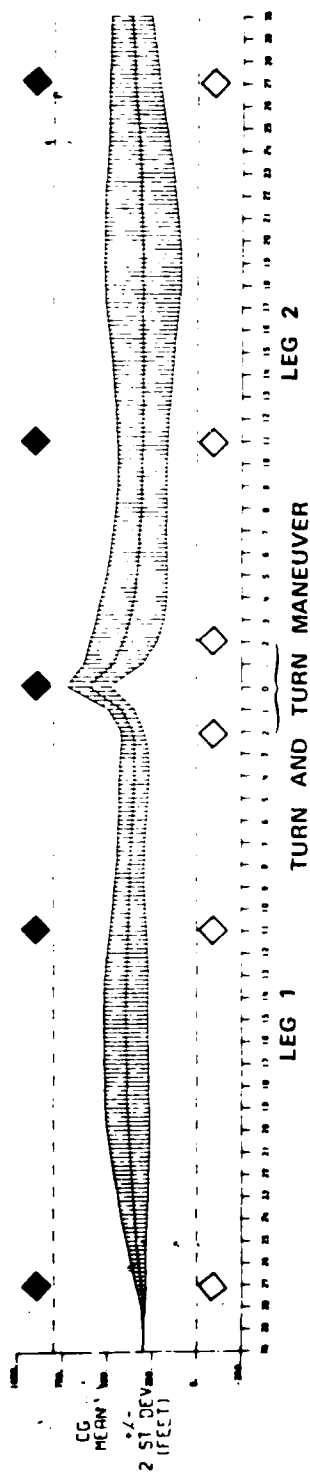
SRA Scenario 6 was also compared to CW 6 to evaluate piloted performance with a 30,000 and 80,000 dwt ship in an 800-foot channel. The constant conditions are identified by Table E-5.

TABLE E-5. CONSTANT CONDITIONS FOR COMPARISON BETWEEN
30,000 AND 80,000 DWT SHIP IN 800-FOOT CHANNEL

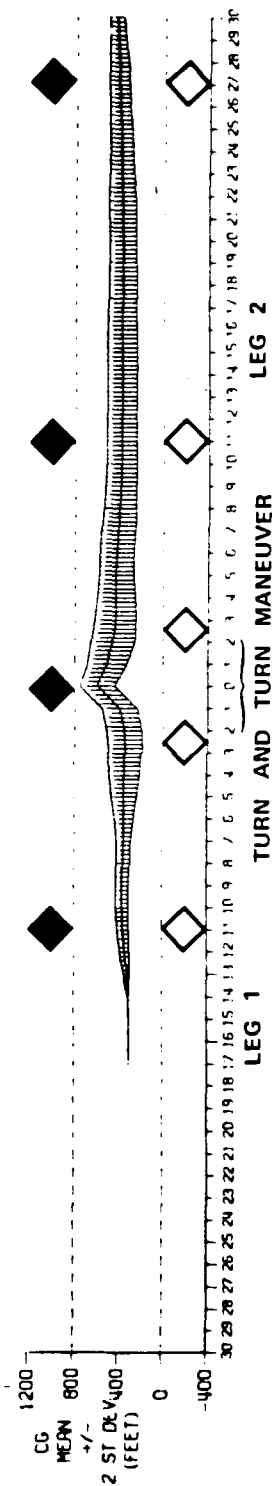
| | |
|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Channel dimensions: | <ul style="list-style-type: none"> • 800-foot width • 1-foot underkeel clearance • 35-degree noncutoff turn |
| 2. Channel markings: | <ul style="list-style-type: none"> • gated buoys spaced at 1-1/4 nm marking the straight legs • 3 buoys marking the turn |
| 3. Environmental effects: | <ul style="list-style-type: none"> • following current changing to port quarter • daytime • 1-1/2 nm visibility |

Both the 30,000 and the 80,000 dwt vessels were piloted successfully in the 800-foot channel as indicated by Figure E-5. Table E-6 shows statistical differences in performance. Surprisingly, piloted performance is poorer with the smaller vessel. The mean and standard deviation through much of Leg 2 is set close to 100 feet off the centerline, and the standard deviation of the tracks is also 100 feet at its widest. There are several factors which may impact pilot performance in the Channel Width scenarios, these are discussed below.

In Leg 1, CW 6 started 1 nm further from the turn than SRA 6 but with the same 100 feet offset. The data is not comparable until the first gated buoys before the turn at Data Line 11. Figure E-5 shows that when passing through the gates the 30,000 was on the centerline. After this point, the mean track moved to right to position the ship for the turn. With the 80,000 dwt ship, pilots never found the centerline but they also initiated the turn to the right of centerline. In turn initiation, track dispersion



CW6: 30K IN 800 FOOT CHANNEL WITH GATES AT 1 1/4 NM



SRA6: 80K IN 800 FOOT CHANNEL WITH GATES AT 1-1/4 NM

NOTE: SCALES FOR THE 800 FOOT CHANNELS ARE DIFFERENT

Figure E-5. Pilot Performance in 800-Foot Channel With 1-1/4 nm Gated BuOys for 30,000 Versus 80,000 dwt Tankers

TABLE E-6. STATISTICAL DIFFERENCES IN PILOTED PERFORMANCE
WITH 30,000 AND 80,000 DWT SHIP IN 800-FOOT CHANNEL

MEAN TRACKS

| Ship Size | LEG 1 | | TURN | | LEG 2 | |
|-----------|--------------------------------|-----------------------------------|--------------------------------|----------------------------|--------------------------------|--|
| | Trackkeeping Data Line Mean | Turn Initiation Data Line Mean | Turn Pullout Data Line Mean | Recovery Data Line Mean | Trackkeeping Data Line Mean | |
| 30,000 | 6 41R | 3 56R | 3 28R | 10 96R | 28 41R | |
| 80,000 | 6 50R | 3 58R | 3 34L | 10 17R | 28 26L | |

STANDARD DEVIATION

| Ship Size | LEG 1 | | TURN | | LEG 2 | |
|-----------|------------------------------|---------------------------------|------------------------------|--------------------------|------------------------------|--|
| | Trackkeeping Data Line SD | Turn Initiation Data Line SD | Turn Pullout Data Line SD | Recovery Data Line SD | Trackkeeping Data Line SD | |
| 30,000 | 5 41 | 3 38 | 3 94 | 6 78 | 28 65 | |
| 80,000 | 5 59 | 3 78 | 3 95 | 7 76 | 28 42 | |

Arrows indicate statistical difference at the level of confidence.

is significantly higher with the 80,000 dwt tanker indicating that pilots used different techniques to bring the large ship around the turn.

Throughout most of Leg 2 the mean tracks of the two ships are statistically different with the 30,000 performing poorly. The mean track is offset by approximately 100 feet with the 30,000, while with the 80,000 the mean track is generally within 20 feet of the centerline. The standard deviation is also wider when piloting with the 30,000 but this is not statistically different from that of the 80,000. One explanation for this is the wind in the Channel Width scenarios is different than that of the other experiment. (See Section 3 of the Ship Variables report for a more detailed discussion.) A second explanation is that the midship wheelhouse may yield a poor perception of position in a wide channel, since there is less ship available to gauge ship position.

E.6 SUMMARY

To evaluate the interaction between channel width and ship size, an analysis of performance differences between the four cells identified at the beginning of this section is necessary. The scenarios selected from the cells include OS 1, the 30,000 dwt ship in the 500-foot channel; CW 6, the 30,000 dwt ship in the 800-foot channel; SV 7, the 80,000 dwt ship in the 500-foot channel; and SRA 6, the 80,000 dwt ship in the 800-foot channel. Piloted differences are most pronounced in the turn pullout and recovery regions of Leg 2. Figures E-7 and E-8 show the turn pullouts recovery from the turn by comparing ship distance away from the turn buoy. With the 80,000, the pilot makes the same turn regardless of channel width; ship size determines strategy. With the 30,000 dwt ship, pilots vary their turn strategies as a function of channel width because the ship is small, maneuverable, and easily adaptable.

Piloted performance with the 30,000 dwt ship is best in the 500-foot channel with piloting precision worsening as channel width increases. In the 500-foot channel, the pilot can easily and precisely bring the ship through the turn and onto the new leg. In the turn pullout, shown in Figure E-7, the mean track is 59 feet right of centerline and the standard deviation is 34 feet. When piloting the 30,000 dwt ship in the 800-foot channel, the mean is closer to the centerline (28 feet right), the standard deviation is almost three times higher (94 feet). In the recovery region, shown by Figure E-8, the mean track is 104 feet off the centerline with a 36-foot standard deviation in the 500-foot channel. In the 800-foot channel, the mean is also approximately 100 feet right of centerline but the standard deviation is approximately double that of the 500-foot channel at 70 feet. In the wide 800-foot channel and a small easy to maneuver ship, the turn is easily maneuverable so piloting strategies are varied (resulting in the higher standard deviation). It appears at least two piloting strategies are used in the 800-foot channel. One was to make the turn identically to that in the 500 foot channel and steady up on the centerline in the new leg. The second was to make the turn wider (closer to the 400-foot centerline) and maneuver centerline to centerline. The deterioration in performance in the wider channel is due either to perceptual difficulties or to the different wind run in the channel width scenarios.

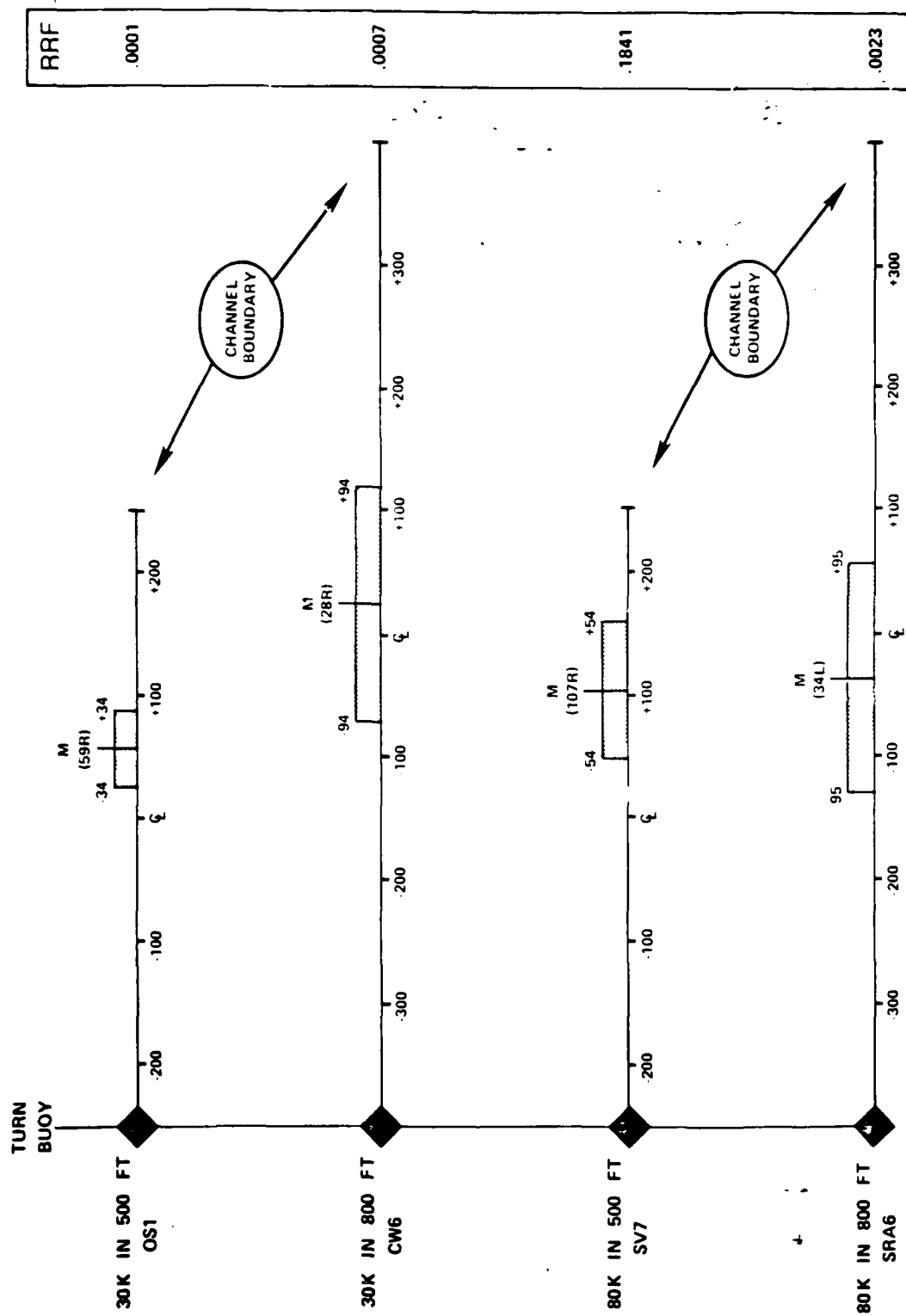


Figure E-7. Ship Size and Channel Width Interaction at Turn Pullout

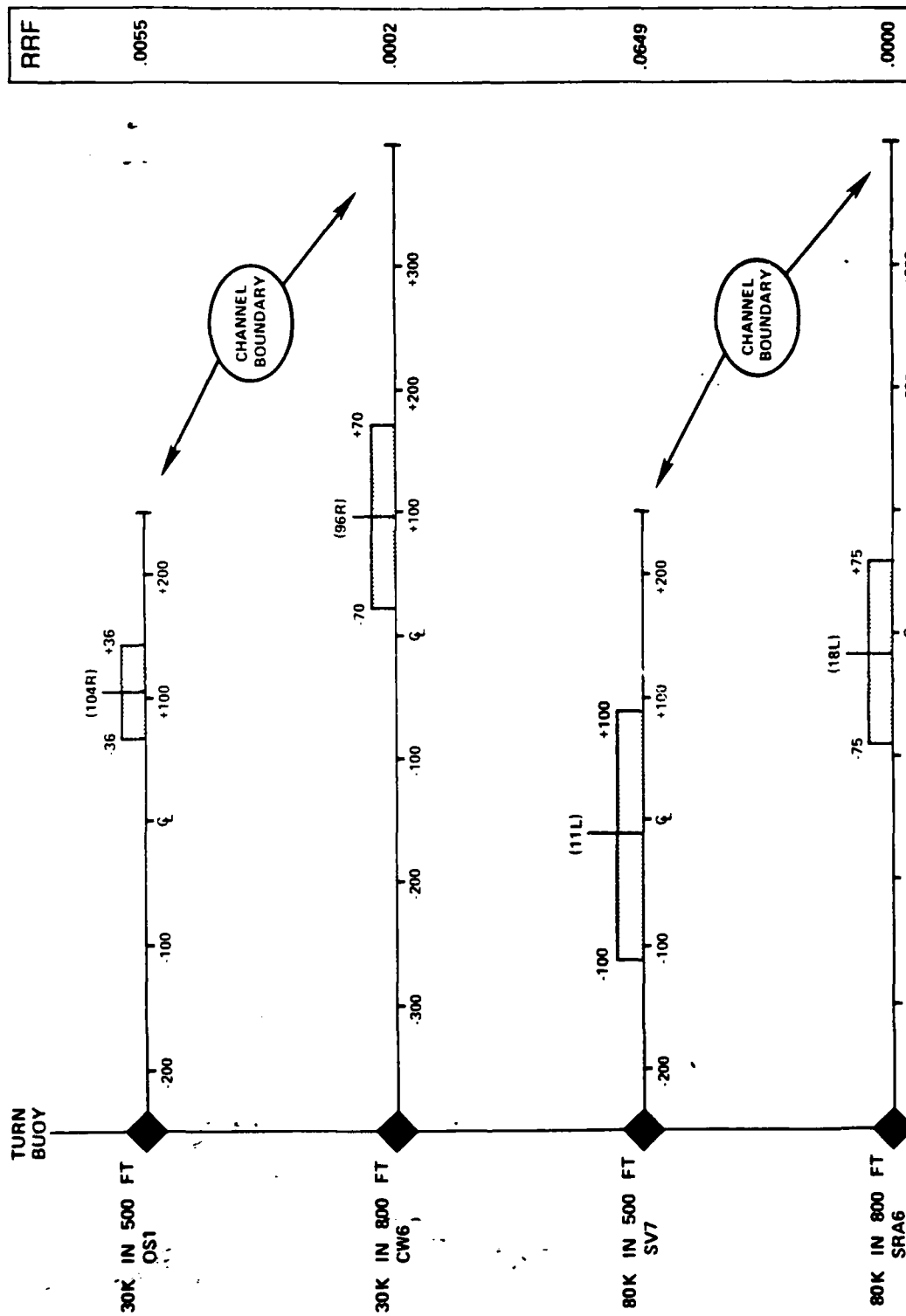


Figure E-8. Ship Size and Channel Width Interaction at Recovery in Log 2

Piloted performance with the 80,000 dwt ship is more "risky" in the 500-foot channel than performance in the 800-foot channel. Figures E-7 and E-8 show the pilots make the same turn with the 80,000 dwt ship regardless of channel width. This is evident by the mean and standard deviation position in Figure E-7. In the 500-foot channel, although the centerline is 250 feet from the turn buoy, the pilots take another 107 feet to maneuver for the turn so the mean track is 357 feet from the turn buoy. In the 800-foot channel, the mean is only 9 feet further right or 366 feet from the turn buoy. Although the mean tracks are essentially the same distance away from the turn buoy, in the 500-foot channel it is 107 feet right of centerline as compared to 37 feet left of centerline in the 800-foot channel. This significantly lowers the relative risk of the 80,000 dwt in the 800-foot channel from that of the 500-foot channel. The relative risk is also lower in the 800-foot channel in the recovery as shown by Figure E-8. This is again due to a similar mean track in both channels but a different offset from the centerline due to channel width. The lower relative risk is due to more channel available to the pilot.

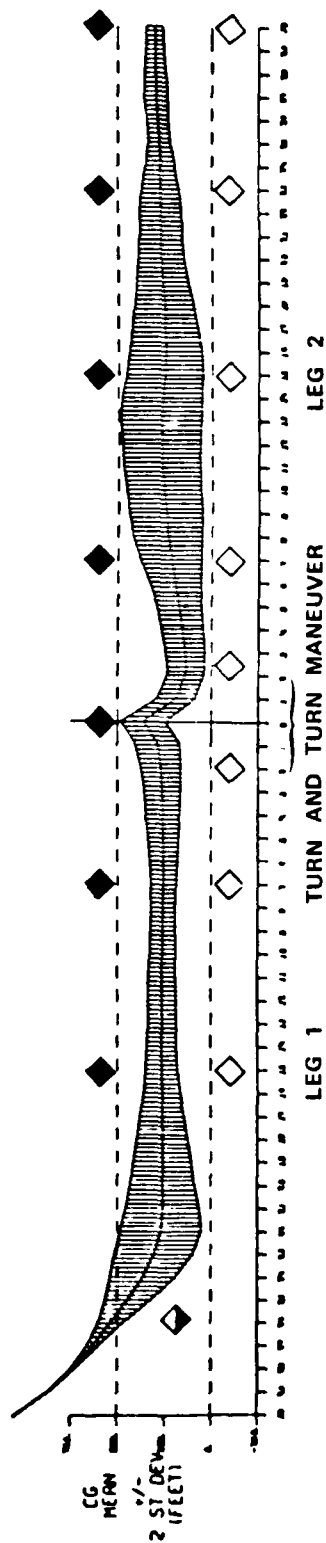
Appendix F
PILOTED PERFORMANCE AS A FUNCTION OF TURNMARKING

F.1 PILOTED PERFORMANCE WITH THE THREE-BUOY TURN

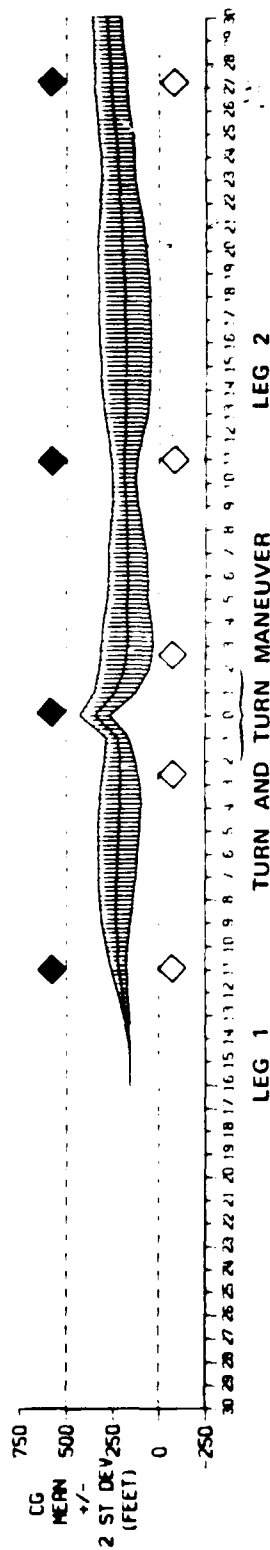
Piloted performance with the three-buoy turn and the 30,000 dwt ship at day versus night was discussed in Section 2 of the Turn Lighting Principal Findings Report.³⁵ By comparing Scenario 1 from the One Side Experiment (day) to Scenario 1 of the Turn Lighting Experiment (night), it was determined that piloting strategies differed at day and at night due to differing visual information. In the daytime, the visual information necessary to guide pilots is available in both higher quality and quantity than nighttime. Pilots in the daytime condition can afford to make a more gradual maneuver, transiting closer to the channel edge, but using less rudder. At night, the pilots compensate for "impoverished" visual cues by adapting a more conservative strategy to attempt to stay closer to the center of the channel and by using more rudder to increase their margin of safety from either channel edge. Although the pilots use a more conservative strategy at night, the standard deviation was high due to difficulties judging the rate of swing, location of channel edges, and the relationship of the ship to the channel edge.

Piloted performance with the three-buoy turn and the 80,000 dwt ship at day versus night is shown by Figure F-1. The SRA Scenario 8 was run in this experiment and consists of the 80,000 dwt at night, and SV 7 is the 80,000 dwt ship at day. Overall performance is worse with the 80,000 dwt ship in the day than at night. Possible explanations for this: (1) run order of the ship variables experiment randomized the order of the ships so the 80,000 dwt ship scenarios did not necessarily follow the familiarization run, (2) the start point of the SV scenarios was outside the channel so a more severe maneuver was required to achieve a centerline track, and (3) after the Ship Variables Experiment, the 80,000 dwt bow image was revised to provide more perceptual cues. In initiating the turn in day, the 80,000 dwt ship was to the left of the centerline and at night it was right of the centerline. This is probably due to experimental differences such as those mentioned above rather than to strategy differences. In the turn pullout and turn recovery, the mean and standard deviation are better with the 80,000 dwt ship at night, although the differences are not statistically significant. As listed in Table F-1, the relative risk is lower at night than at day. This value is deceiving because pilots have less perceptual information at night. It appears that at night with the large 80,000 dwt ship in a proportionally narrow 500-foot channel, the pilots concentrate more on keeping the ship in the center of the channel and away from the channel boundaries. Therefore, in adverse conditions the pilots are stricter and work harder to keep the ship on the centerline in a safe zone.

³⁵J. Muilter and M.W. Smith, op. cit.



SV7: 80,000 DWT SHIP AT DAY, 3 BUOY TURN



SRA8: 80,000 DWT SHIP AT NIGHT, 3 BUOY TURN

1 DATA LINE = 475 FEET

Figure F-1. 80,000 DWT Ship with the 3 Buoy Turn, Day Versus Night

TABLE F-1. PULLOUT PERFORMANCE FOR TURNMARKING, SHIP SIZE, AND DAY/NIGHT

| | Day | | | | | | Night | | | | | |
|--------------------------------|------------------|----------|-----------|------|--------------------|----------------------|------------------|----------|-----------|------|--------------------|----------------------|
| | Experiment | Scenario | Data Line | Mean | Standard Deviation | Relative Risk Factor | Experiment | Scenario | Data Line | Mean | Standard Deviation | Relative Risk Factor |
| 30,000 dwt ship Three buoys | One-Side | 1 | 3 | 59R | 34 | 0.0001 | Turn Light | 1 | 2 | 8R | 56 | 0.0012 |
| | One-Side | 6 | 3 | 94R | 33 | 0.0035 | Turn Light | 8,9 | 3 | 28R | 67 | 0.0110 |
| | Ship Variables | 2 | 3 | 72R | 45 | 0.0068 | SRA Supplemental | 9 | 3 | 6R | 73 | 0.0126 |
| | | | | | | | | | | | | |
| 80,000 dwt ship Three buoys | Ship Variables | 7 | 3 | 107R | 54 | 0.1841 | SRA Supplemental | 8 | 3 | 79R | 70 | 0.1383 |
| | SRA Supplemental | 7 | 3 | 81R | 45 | 0.0485 | Turn Light | 10 | 3 | 187R | 58 | 0.7019 |
| | Ship Variables | 6 | 3 | 137R | 65 | 0.3859 | | | | | | |
| | | | | | | | | | | | | |

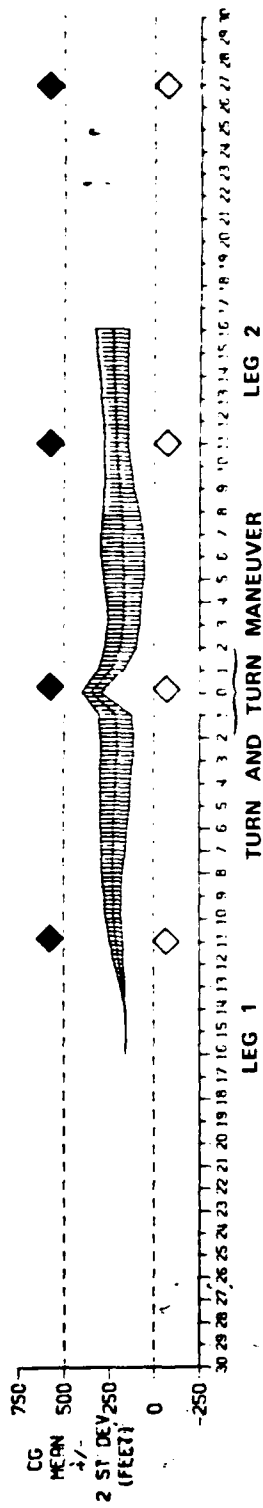
F.2 PILOTED PERFORMANCE WITH THE TWO-BUOY TURN

Piloted performance with the two-buoy turn and the 30,000 dwt ship at day versus night was discussed in Section 2 of the Turn Lights Principal Findings Report. Again, it was found that performance was more conservative at night with pilots concentrating on keeping the ship on the centerline. At night, the mean track was closer to the centerline at the pullout, but the standard deviation was double that during the day indicating pilot uncertainty regarding ship position in the channel.

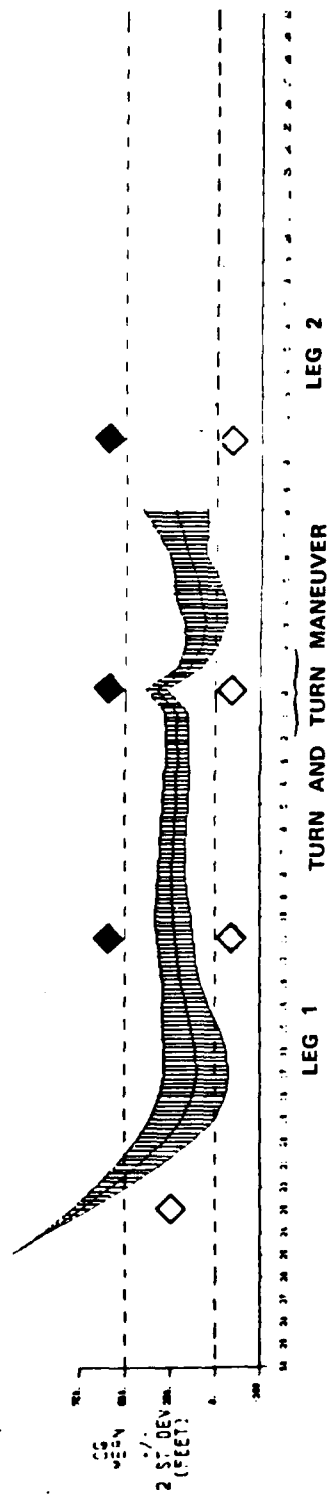
Piloted performance with the two-buoy turn and the 80,000 dwt ship at day versus night is shown by Figure F-2. The SRA Scenario 7 was run in this experiment and consists of an 80,000 dwt ship transiting through the two-buoy turn at day. Performance is satisfactory with the 80,000 dwt ship in the day, but performance is poor at night. At turn initiation, from Data Line 5 to the turn maneuver, performance is similar. In the turn pullout, however, the mean track of the 80,000 dwt ship at night (187Right) is significantly worse than that at day (81Right). The 80,000 dwt ship is difficult to maneuver so as information decreases, by decreasing lighting and therefore visual cues, performance worsens. At night, with the mean set far to the right of the channel, and the 60-foot standard deviation, some tracks are set outside the channel for 1425 feet. At night with the larger ship, pilots are unable to compensate adequately for the uncertainty of the outside channel edge.

Piloted performance with the two-buoy turn can also be compared to determine the effect on ship size. The 80,000 dwt ship in SRA 7 is compared to the 30,000 dwt ship in OS 6 in Figure E-3. Piloted performance is satisfactory with both ships and the two-buoy turn at day. As is summarized in Table F-1, turn pullout performance is similar with both ships with the RRF higher with the 80,000 dwt ship. The mean track is slightly better with the 80,000 dwt ship, perhaps due to more ship length to gauge ship's position and lateral set. The standard deviation is higher for the 80,000 dwt ship although this is not statistically significant.

In the Turn Lighting Experiment, TL 8 and TL 10 were compared to evaluate piloted performance differences between the 30,000 and 80,000 dwt ship at night. Performance was worse with the 80,000 because at night, where the ship is more difficult to handle, the pilot is more dependent upon navigational aids for guidance through the turn. If a large ship enters the channel at night, he may need more than two buoys to make a 35-degree noncutoff turn and stay in the channel. See Section 4.3 of the Turn Lights Experiment for further discussion of performance differences and the two-buoy turn at night.



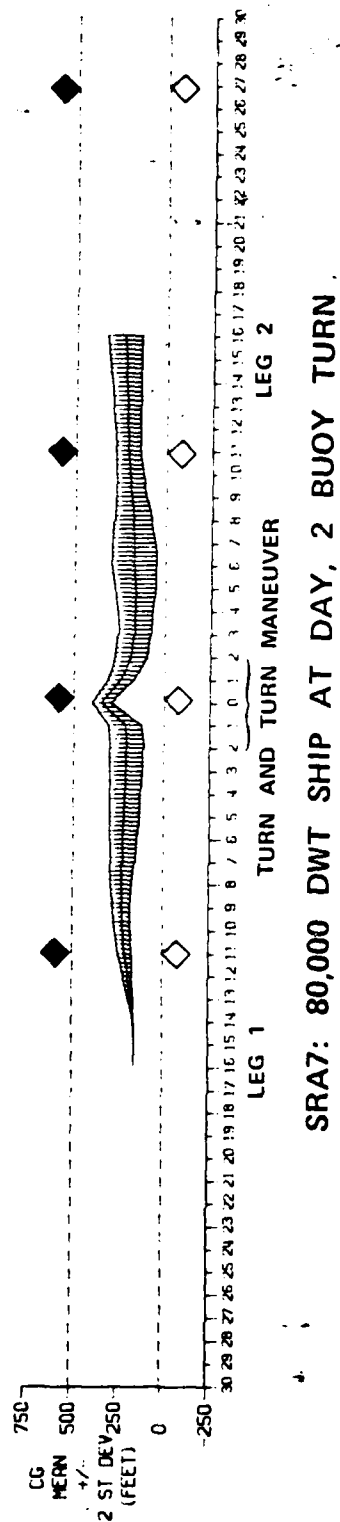
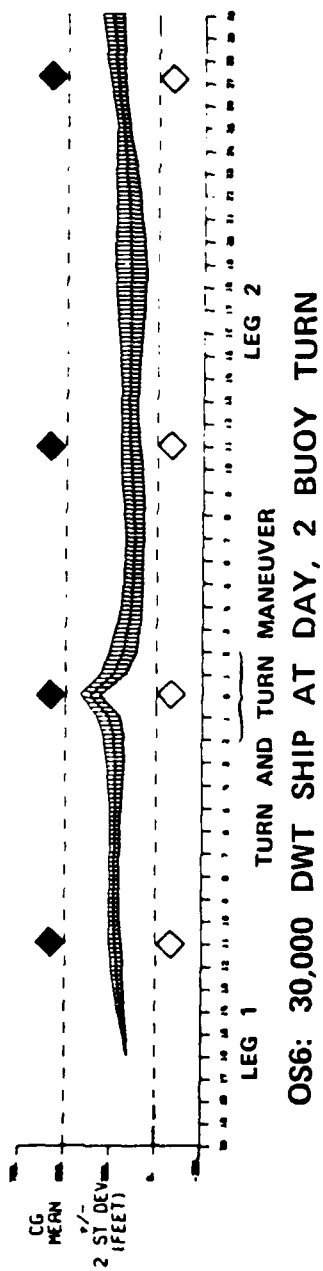
SRA7: 80,000 DWT SHIP AT DAY, 2 BUOY TURN



TL10: 80,000 DWT SHIP AT NIGHT, 2 BUOY TURN

1 DATA LINE = 475 FEET

Figure F-2. 80,000 DWT Ship With 2 Buoy Turn, Day Versus Night



1 DATA LINE = 475 FEET

Figure F-3. 30,000 Versus 80,000 DWT Ship with 2 Buoy Turn in Day

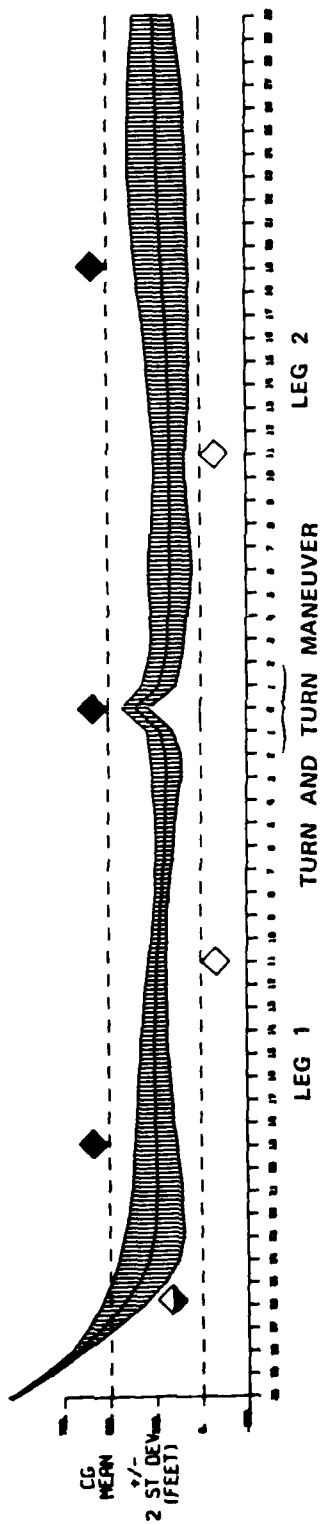
F.3 PILOTED PERFORMANCE WITH THE ONE-BUOY TURN

Three scenarios are available to evaluate piloted performance with the one-buoy turn. These are: SV 2 which is the 30,000 dwt ship at day, SRA 9 which is the 30,000 dwt ship at night, and SV 6 which is the 80,000 dwt ship at day. Piloted performance is acceptable with the 30,000 dwt ship at day, but at night performance is barely satisfactory with some ship tracks skirting the channel boundary in setting up for the turn. Piloted performance with the 80,000 dwt ship at day is unsatisfactory with the ship tracks exiting the channel for 2850 feet in the turn pullout. Appendix C of this report and Section 5 of the Ship Variables report details piloted performance in the Ship Variables scenarios (SV 2 and SV 9).

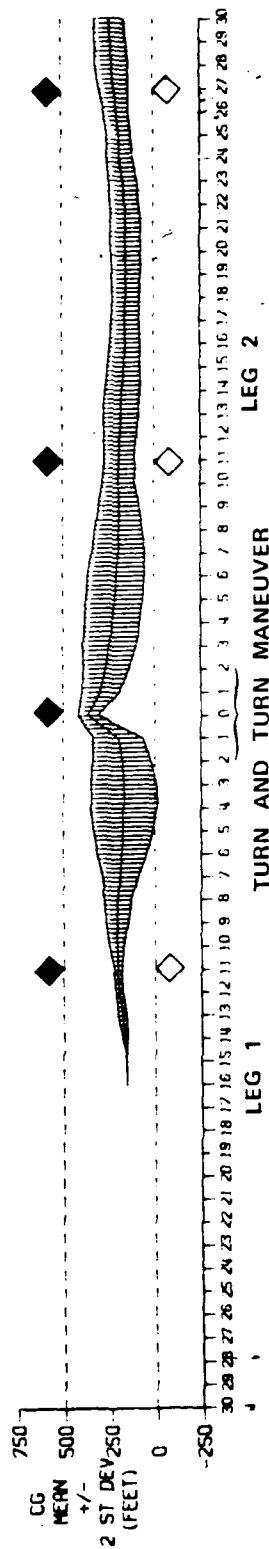
Piloted performance with the one-buoy turn and the 30,000 dwt ship at day versus night is shown by Figure F-4. In setting up for the turn, the standard deviation for the 30,000 dwt ship at night was more than double that of the 30,000 at day between Data Lines 6 through 13. This may be due to the SRA initialization since at night with one buoy pilots do not trackkeep. They attempt to find the centerline and then set up for the turn (earlier than most other scenarios). The wide standard deviation at this point indicates pilot uncertainty of where to begin the turn and the strategy to use. In the turn, the pilots stayed closer to the turn buoy at night (SRA 9). Consequently, at the turn pullout the mean was significantly better at night than during the day. Table F-1 shows in the turn pullout the mean of the 30,000 dwt ship at day was 72 feet to the right of the centerline as compared to 6 feet to the right at night. The standard deviation is larger at night than at day but it is not statistically significant, however, this is reflected by the higher RRF at night. It should be noted that the RRF may still be deceptively low at night because the pilots not only try harder to maintain a centerline track, they also turn harder. See Section 2.2 in the Turn Lights Principal Findings Report for a description of piloting strategies in the turn at day and at night.

F.4 SUMMARY

In conclusion, a turn marked by one-buoy is only acceptable for ships transiting at night with a 30,000 dwt ship or smaller. For ships 80,000 dwt or larger, a three-buoy turn is recommended for nighttime transits. During the day two- and three-buoy turns produce acceptable tracks for the 30,000 through 80,000 dwt ships. At day, the one-buoy turn results in acceptable tracks for the 30,000 through 52,000 dwt ship, but performance is not acceptable with the 80,000 dwt ship.



SV2: 30,000 DWT SHIP AT DAY, 1 BUOY TURN



SRA9: 30,000 DWT SHIP AT NIGHT, 1 BUOY TURN

1 DATA LINE = 475 FEET

Figure F-4. 30,000 DWT Ship with 1 Buoy Turn, Day Versus Night

Appendix G
EFFECT OF DESIGN CONDITIONS ON PILOTED PERFORMANCE

G.1 OVERVIEW

Early in the AN project it was hypothesized that differences in the performance of aid arrangements would not be revealed by easy shiphandling tasks. Only difficult shiphandling tasks that forced the pilot to depend on the buoys (or other aid systems) for timely information as to his ship's position and status would reveal differences. The basic experimental scenario was designed with relatively difficult "design conditions." That is, they were run with a slow 6 knots, with 1 foot underkeel clearance, and, in a part of the scenario, a crosstrack wind and current. The design conditions are illustrated in Appendix B.

Because the difficult design conditions would not be expected to occur in the real world with any high frequency, they build a degree of conservatism into the data and into the manual. An objective of this experiment is to evaluate the degree of conservatism of the "basic" scenario by comparing the design conditions to conditions more representative of those that would be expected to occur with a higher frequency in the real world. This evaluation of the difference between design and representative conditions is conceptually related to validation, an evaluation of the difference between simulator and at-sea data.³⁶ This section will first compare performance for the difficult shiphandling requirements imposed by the design conditions with a more representative set of shiphandling requirements to evaluate the degree of conservatism. The newly available data for representative conditions can also be compared to a Radar I³⁷ scenario run to test design conditions under the very limited visibility in that experiment.

G.1 EFFECT OF DESIGN CONDITIONS IN 1-1/2 NM VISIBILITY

The representative conditions were run in Scenario 10 of this experiment. The design condition scenario chosen for comparison was OS 1, a scenario that has been used several times in this report. The two scenarios differed as follows:

| Variable | SRA 10: Representative Conditions | OS 1: Design Conditions |
|-------------------------------------------------------|---------------------------------------|----------------------------------------------------------------------------------------------|
| Ship speed Underkeel clearance Wind and current | 10 knots 10 feet underkeel None | 6 knots 1 foot underkeel Current 1.2 knots and decreasing Wind 30 knots and gusting |

³⁶M.W. Smith, K.L. Marino, J. Multer and J.D. Moynehan. "Aids to Navigation Draft Principal Findings Report: Validation for a Simulator-Based Design Project." U.S. Coast Guard, Washington, D.C., March 1984.

³⁷J. Multer and M.W. Smith, op. cit.

The constant conditions for this comparison are listed in Table 6-1.

TABLE G-1. CONSTANT CONDITIONS FOR DESIGN CONDITIONS COMPARISON

| | |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| 1. Channel dimensions: | <ul style="list-style-type: none">• 500-foot width• 35-degree noncutoff turn |
| 2. Environmental effects: | <ul style="list-style-type: none">• daytime• 1-1/2 nm visibility |
| 3. Channel markings: | <ul style="list-style-type: none">• gated buoys spaced at 1-1/4 nm intervals• 3 buoys marking the turn |
| 4. Ship: | <ul style="list-style-type: none">• 30,000 dwt tanker• midship wheelhouse |

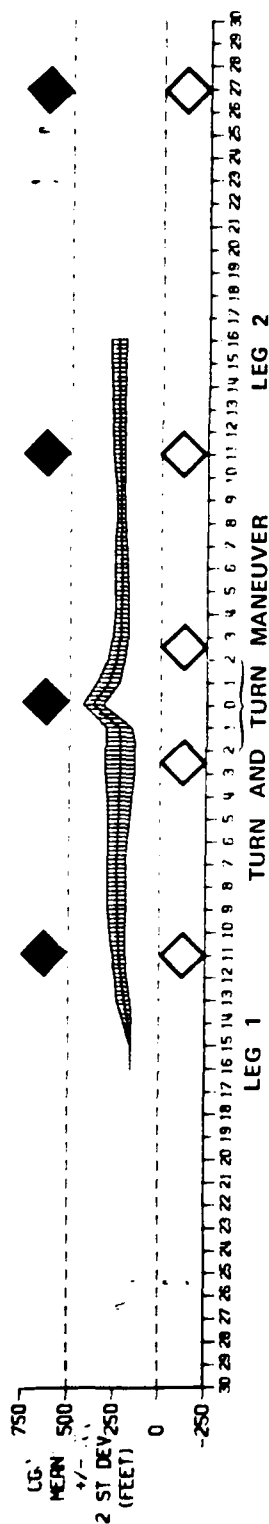
Both scenarios resulted in good performance with the 30,000 dwt ship and long-spaced gated buoys with a three-buoy turn as indicated by Figure G-1. In Leg 1, there are no significant differences between ship tracks. The turn is initiated in approximately the same location; however, the standard deviation is slightly higher in the representative scenario (SRA 10). In the turn pullout differences become apparent with the mean track of OS 1 being set over 90 feet right of centerline due to wind and current and possibly to the slow 6-knot speed. (See Section 3 and Appendix D of this report for a discussion of ship speed and its effect on piloted performance.) Performance differences occur throughout Leg 2, with the wind and current setting the ship tracks further to the right with an offset of over 75 feet. With no wind and current in the SRA 10 scenario pilots can keep the ship with 25 feet of the centerline through most of the run.

The design conditions do present a more difficult shiphandling problem, especially in the turn pullout and recovery. This difficulty shows in performance even with a density and arrangement of buoys that are among the best evaluated.

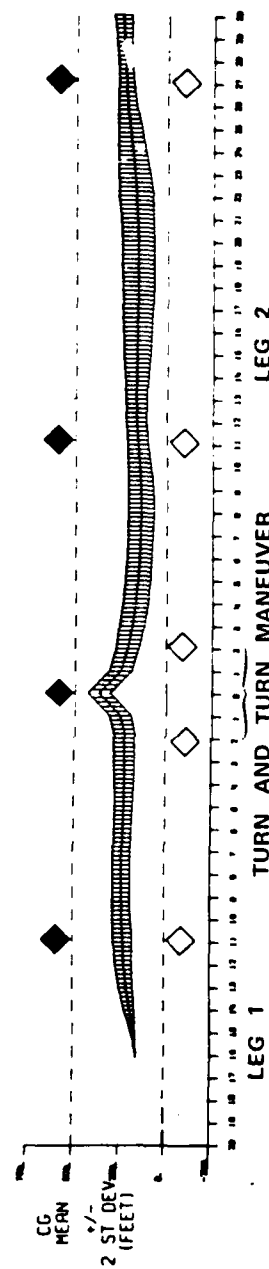
G.2 EFFECT OF VISIBILITY UNDER REPRESENTATIVE SHIPHANDLING CONDITIONS

The Radar I Experiment also included a scenario with representative, rather than design, shiphandling requirements. In that experiment Scenario 4 was run with 1/4 nm visibility and radar. A "representative" speed under such visibility is 6 knots rather than 10. This scenario differed from SRA 10 as follows:

| Variable | Representative Conditions | |
|------------|---------------------------|---------|
| | SRA 10 | RI 4 |
| Visibility | 1-1/2 nm | 1/4 nm |
| Radar | No | Yes |
| Ship Speed | 10 knots | 6 knots |



SRA10: 30K SHIP, DAY, NO WIND OR CURRENT,
10 KNOTS, 10 FEET UNDER KEEL CLEARANCE



OSI: 30K SHIP, DAY, WIND & CURRENT,
6 KNOTS, 1 FOOT UNDER KEEL CLEARANCE

Figure G-1. Effect of Design Conditions in 1-1/2 nm Visibility

Constant conditions between the two scenarios are summarized in Table G-2.

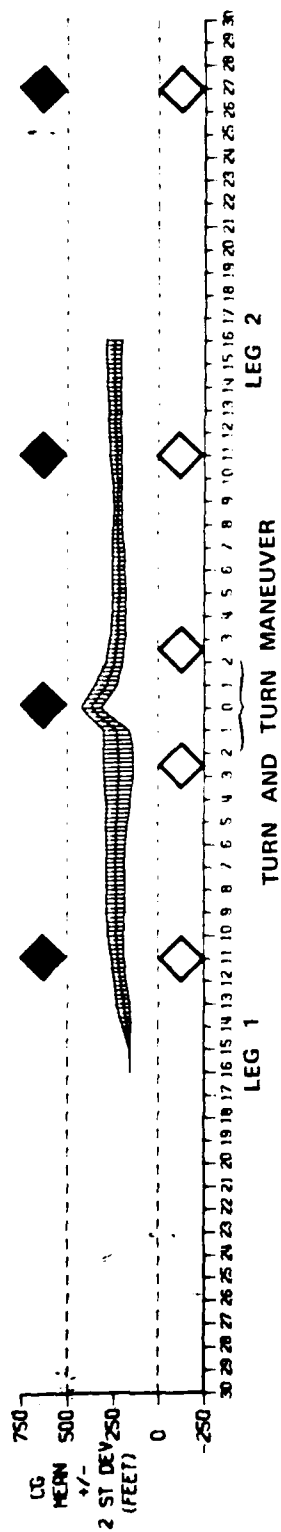
TABLE G-2. CONSTANT CONDITIONS FOR NO WIND AND CURRENT COMPARISON

| | |
|---------------------------|------------------------------------------------|
| 1. Channel dimensions: | ● 500-foot width ● 35-degree noncutoff turn |
| 2. Environmental effects: | ● daytime ● no wind or current |
| 3. Channel markings: | ● gated buoys ● 3 buoys marking the turn |
| 4. Ship: | ● 30,000 dwt tanker ● midship wheelhouse |

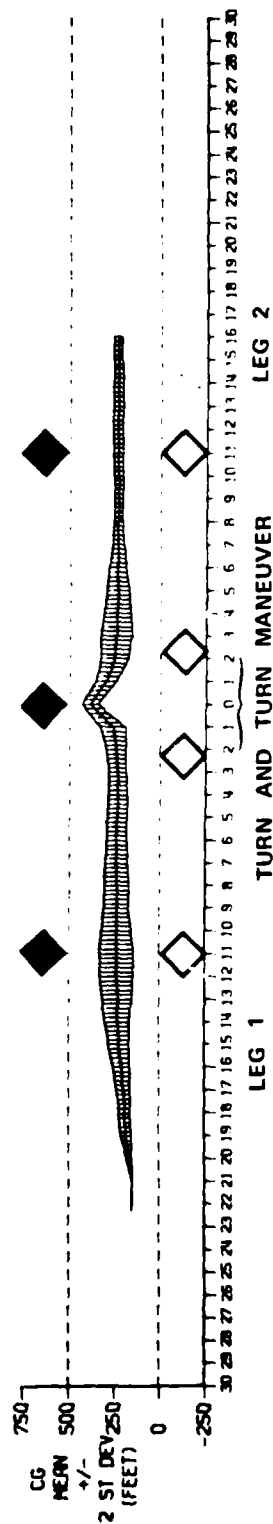
Piloted performance in the two scenarios is shown by Figure G-2. Performance is similar in the scenarios despite the major difference in visibility/radar conditions. Overall, performance is excellent in both scenarios with mean tracks very close to the centerline and the standard deviation small. The tracks are very similar with few statistical differences. The similarity of performance under such extreme differences in piloting information available, but with undemanding shiphandling requirements, is strong support for the initial hypothesis that demanding shiphandling tasks are necessary to force performance differences between alternative aid arrangements.

G.3 SUMMARY

Performance was more precise under the more representative shiphandling conditions. There is a conservatism in the manual and a safety margin because of the low frequency environmental or shiphandling events.



SRA10: 30K SHIP, DAY, NO WIND OR CURRENT, 10 KNOTS



RA4: 30K SHIP, DAY, NO WIND OR CURRENT, 6 KNOTS

Figure G-2. Effect of Visibility Under Representative Shiphandling Conditions

Appendix H

SHIP SIZE AND INHERENT CONTROLLABILITY

H.1 COMPARISON OF INHERENT CONTROLLABILITY FACTORS

This appendix contains an analysis and plots of ship response data to determine specific differences among the 30,000, 52,000, and 80,000 dwt ships that were simulated in this experiment. The 30,000 and 80,000 dwt tankers have been described earlier in the Ship Variables Experiment Principal Findings Report Appendices A and B. Here the inherent capability of the 52,000 dwt vessel will be compared with the sea trial characteristics of the smaller and larger simulated ships. The point of these comparisons is to determine whether a particular ship response characteristic is a better predictor of piloted controllability than the ship's displacement, which has been used as the criterion for comparison throughout most of the AN project.

To begin, a few definitions are helpful. "Inherent controllability" is the maneuvering and coursekeeping qualities that are built in or inherent in a vessel, without considering the capability of the shiphandler or its automatic steering system. "Piloted controllability" adds the capability of the shiphandler who may be able to compensate for design limitations of the vessel. Figure H-1 shows a simplified representation of a control loop where the ship is the vehicle to be controlled and the pilot serves as the controller. As indicated, the ship is identified to exhibit certain inherent controllability characteristics. The pilot's only input to the system is control orders. The ship and its systems respond to the orders via transfer functions as defined by the simulation hydrodynamic equations and coefficients. Comparison of these equations and coefficients, unfortunately, does not yield readily understandable differences between ships. Rather response characteristics of the ship are determined by providing a unique set of input control orders (driving functions) and observing the output response. The input functions, for present purposes, are a unique set of rudder commands which are typical of sea trial maneuvers.

Figure H-2 shows system configuration for these tests. Essentially, the ship is being studied in an "open loop," that is without the pilot. Various rudder commands (helm orders) are input and the ship's responses in terms of heading and track are recorded and analyzed. Two principal input maneuvers are studied, the turning circle and Z-maneuver. Plots of these maneuvers are available in Appendix I.

H.2 ANALYSIS OF TURNING CIRCLE MANEUVERS

The turning circle maneuver consists of commanding the rudder to a fixed position right or left from an initial condition of traveling in a straight line with the rudder amidships. The rudder is held in the fixed position until a 180-degree heading change occurs. The response parameters of interest are the following:

- a. Tactical Diameter. Diameter of the turning circle between maneuver initiation and achievement of a 180-degree heading change.

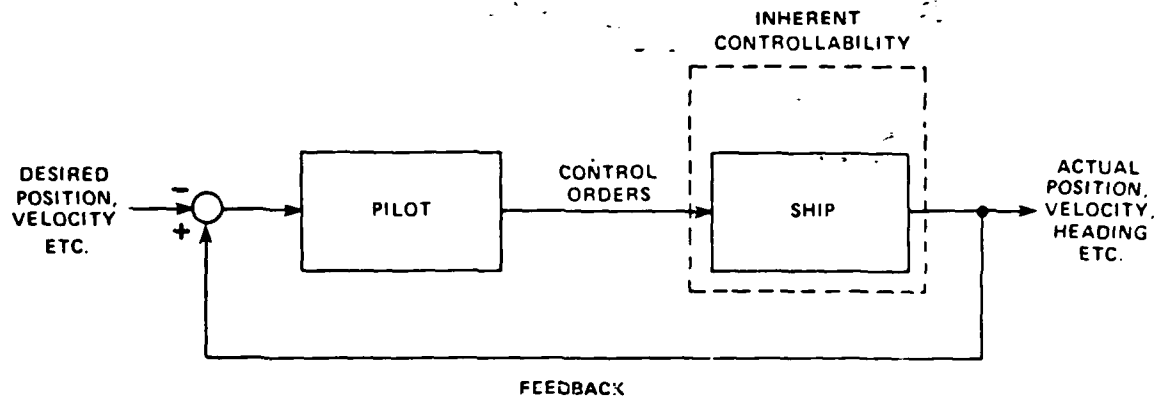


Figure H-1. Simplified Diagram of the Pilot/Ship Control Loop

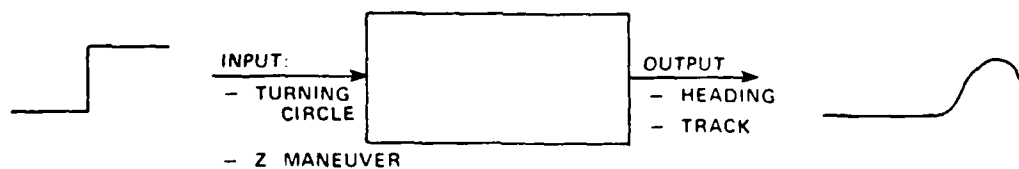


Figure H-2. System Configuration for Simulated Sea Trials

b. Advance. Distance the ship advances between maneuver initiation and achievement of a 90-degree heading change.

c. Transfer. The lateral distance of the ship from the initial path of the ship when a 90-degree heading change is achieved.

Figure H-3 shows the response characteristics for a typical turning circle. Turning circles may be executed at various speeds for different underkeel clearances, and with different rudder angles.

The data in Tables H-1 through H-3 indicate turning circle parameters for the 30,000 dwt, 52,000 dwt and 80,000 dwt tankers with 35 degrees of rudder at 6 and 10 knots. These values were taken from the turning circle plots in Appendix E of this report and Appendix B of the Ship Variables Report. The 52,000 dwt ship, which is the supplementary ship in these experiments, showed excellent turning circle performance with tighter tactical diameters under all conditions than the 30,000 dwt tanker, or to put it in its proper context, with the three ships it can be seen that the 30,000 dwt ship showed relatively poor turning circle controllability. The 52,000 dwt and 80,000 dwt vessels each had tactical diameter/ship length ratios of about 4.9 while the 30,000 dwt ship's ratio was 6.1. Advance and transfer for all show relative performance that would be anticipated and is not meaningfully different.

These turn circle values, while interesting indicators of ship's inherent controllability, it must be noted, did not prove related to the ship's piloted controllability in the Ship Variables Experiment. Therefore, it is not expected they will in this experiment.

H.3 ANALYSIS OF Z-MANEUVER

The Z-maneuver is more complex than the turning circle maneuver and the response parameters are greater in number. This maneuver is executed as a series of rudder deflections based on the resultant heading changes. The typical Z-maneuver is a 20/20 Z-maneuver. From a straight line path with rudder amidships, the helm (rudder command) is deflected 20 degrees to the right. When the heading changes 20 degrees to the right of the initial heading, the helm is reversed to 20 degrees left. When the heading changes to 20 degrees left of the initial heading, the helm is reversed to 20 degrees right. The sequence may be continued any number of times.

Figure H-4 shows the rudder command, heading response, and crosstrack response for a typical Z-maneuver. Three groups of variables can be analyzed for the Z-maneuver. These groups are defined and identified below.

The Turn Response Variables describe the time response, the system time lag intervals, and the rate characteristics of turning. Turn response variables include:

a. Rise Time (T_{20}) = Time interval for the heading to change to 20 degrees right of initial heading measured from the maneuver initiation (seconds).

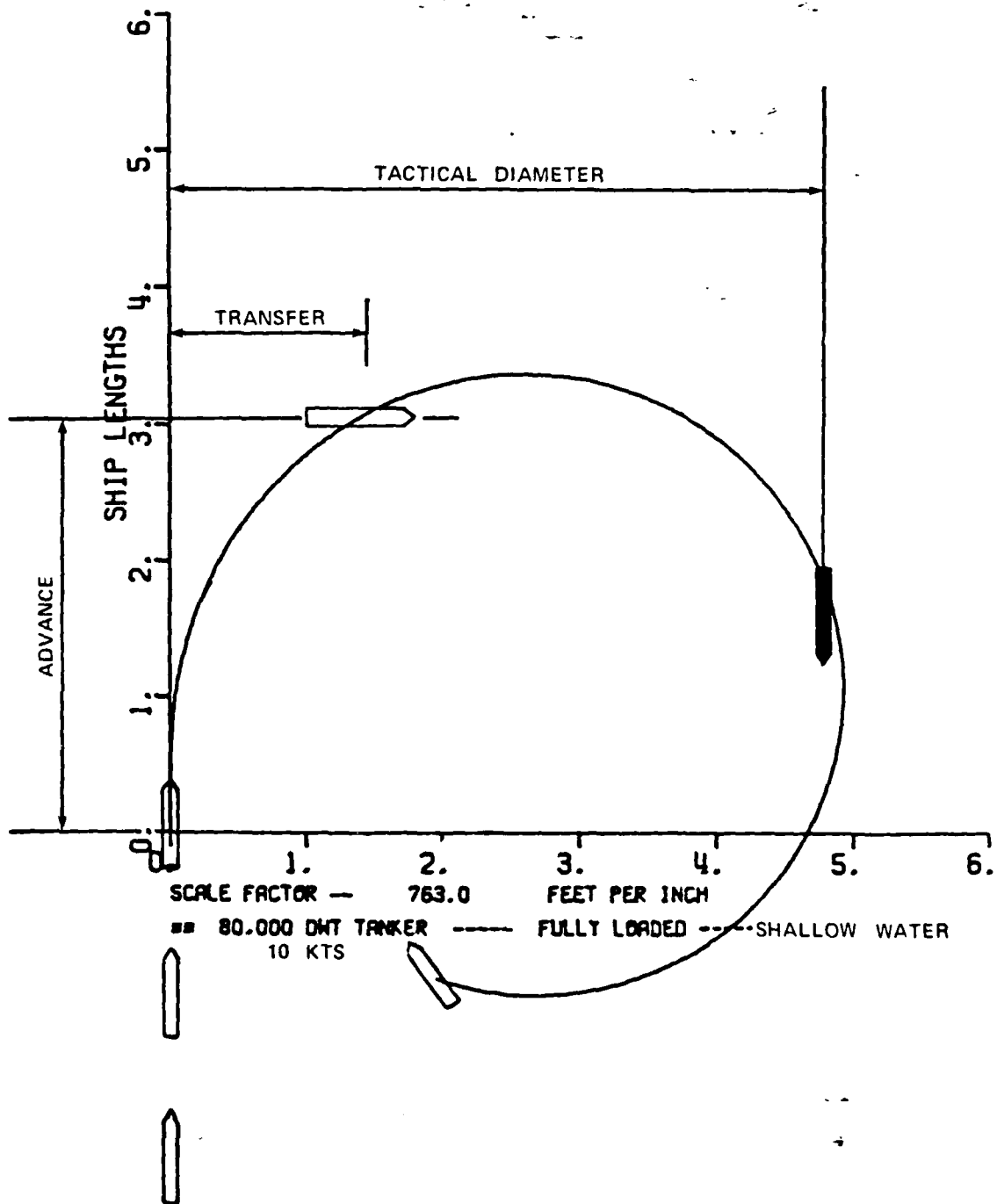


Figure H-3. Response Characteristics for a Turning Circle Maneuver,
35 Degree Right Rudder

TABLE H-1. COMPARISON OF TURN CIRCLES ACROSS SHIP SIZE AND SPEED
WITH 1-FOOT UNDERKEEL CLEARANCE

| Ship Size | 30,000 dwt | | 52,000 dwt | | 80,000 dwt | |
|--------------------------|------------|------|------------|------|------------|------|
| Speed (knots) | 6 | 10 | 6 | 10 | 6 | 10 |
| Tactical diameter (feet) | 3625 | 3657 | 3243 | 3245 | 3753 | 3760 |
| Advance (feet) | 2114 | 2192 | 2298 | 2342 | 2496 | 2558 |
| Transfer (feet) | 1700 | 1811 | 1585 | 1580 | 1790 | 1958 |

TABLE H-2. COMPARISON OF TURN CIRCLES ACROSS SHIP SIZE AND
UNDERKEEL CLEARANCE FOR 6 KNOTS

| Ship Size | 30,000 dwt | | 52,000 dwt | | 80,000 dwt | |
|----------------------------|------------|------|------------|------|------------|------|
| Underkeel clearance (feet) | 1 | 600 | 1 | 600 | 1 | 600 |
| Tactical diameter (feet) | 3625 | 2517 | 3243 | 2391 | 3753 | 2423 |
| Advance (feet) | 2114 | 1811 | 2298 | 2240 | 2496 | 1988 |
| Transfer (feet) | 1700 | 1174 | 1585 | 1108 | 1790 | 946 |

TABLE H-3. COMPARISON OF TURN CIRCLES ACROSS SHIP SIZE AND RUDDER ANGLE
WITH 1-FOOT UNDERKEEL CLEARANCE AT 6 KNOTS

| Ship Size | 30,000 dwt | | 52,000 dwt | | 80,000 dwt | |
|--------------------------|------------|------|------------|------|------------|------|
| Rudder angle (degrees) | 20 | 35 | 20 | 35 | 20 | 35 |
| Tactical diameter (feet) | 4666 | 3625 | 4512 | 3243 | 5650 | 3753 |
| Advance (feet) | 2690 | 2114 | 3173 | 2298 | 3590 | 2496 |
| Transfer (feet) | 2268 | 1700 | 2306 | 1585 | 2745 | 1790 |

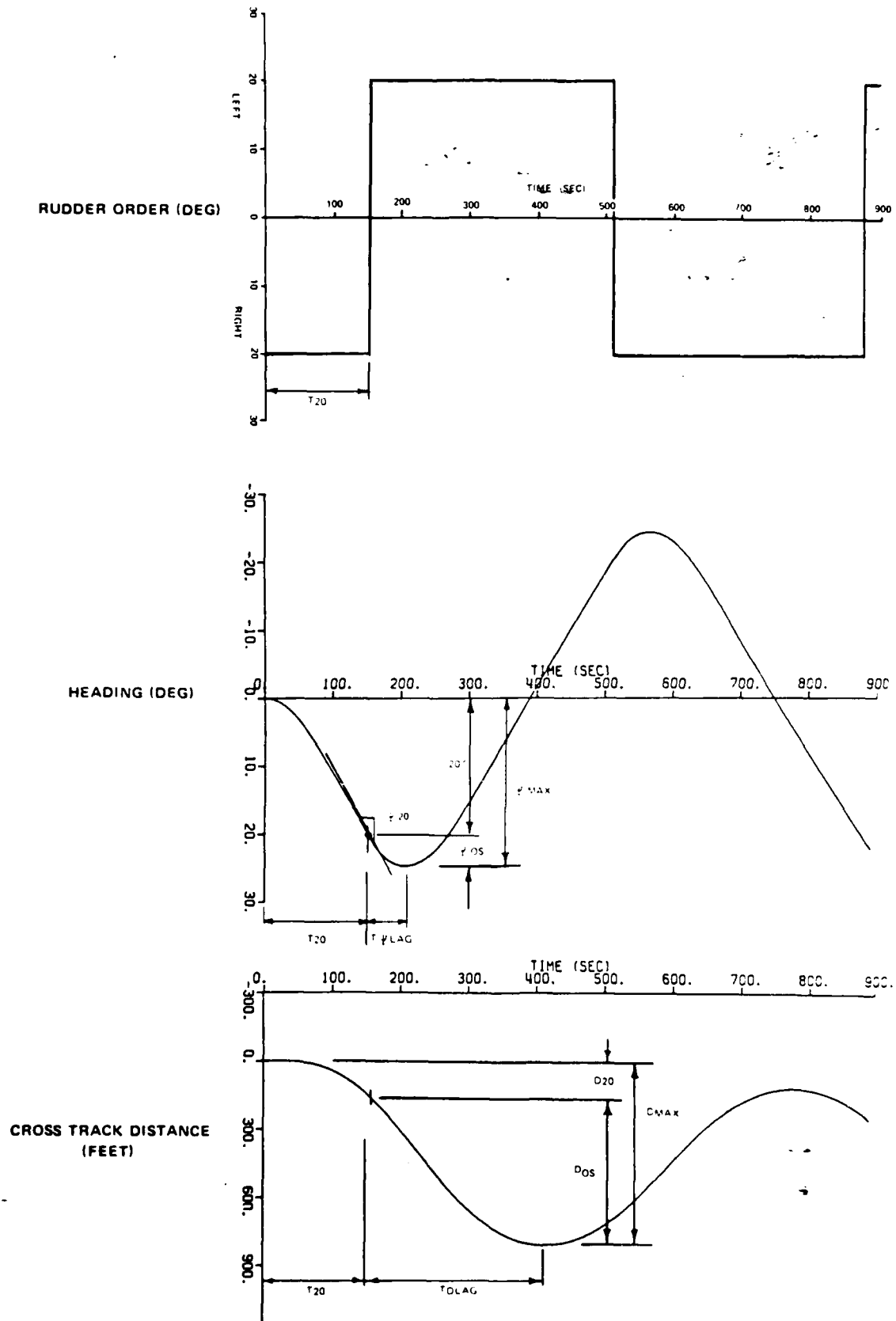


Figure H-4. Typical 20/20 "Z" Maneuver

b. Slew Rate (Ψ_{20}) = The maximum turning rate achieved in the maneuver. It occurs at the point where the ship's heading has just reached 20 degrees right of the initial heading (degrees/second).

c. Heading Lag ($T_{\Psi LAG}$) = The time interval between the first reversal of the rudder command and the maximum heading difference from the initial heading (seconds).

d. Displacement Lag (T_{DLAG}) = The time interval between the first reversal of the rudder command and the maximum crosstrack displacement from the initial track (feet).

These variables indicate the length of time the pilot must anticipate his control actions and the time lag in system response to control orders. In the piloting situation, alongtrack distance traveled is important since these distances are observable and buoy positions relative to the ship's length may be an important preceptual cue to initiating maneuvers and corrective actions. Turn response variables may, therefore, also be expressed as alongtrack distance traveled during the stated time intervals. The time domain variables may be changed to alongtrack distance units through multiplication by ship's average speed. Such variables are said to be expressed in the distance domain.

The Heading Response Variables describe the magnitude and overshoot of the ship's heading following the first rudder reversal. This response is of interest because it is hypothesized that pilots control the ship's track by controlling the ship's heading at various positions along the channel and through the turn. The overshoot data, perhaps, indicate how reliably the pilot can achieve the desired heading by issuing rudder orders. The heading response variables include:

a. Max Heading Excursion (Ψ_{MAX}) = The maximum heading deviation from the initial heading for the first rudder deflection (degrees).

b. Heading Overshoot ($\% \Psi_{OS}$) = The overshoot in heading which occurs after the rudder command is reversed (percent):

$$\% \Psi_{OS} = 100 \Psi_{OS} / 20 \text{ where } \Psi_{OS} = \Psi_{MAX} - 20$$

The Track Response Variables describe the magnitude and overshoot in the crosstrack position of the ship in response to manipulation of the helm. Ultimately, the pilot must control crosstrack position to achieve the desired transit. Control of these variables is achieved indirectly through helm orders and indirectly through control of the ship's heading. The track response variables include:

a. Max Crosstrack Excursion (D_{MAX}) = The maximum crosstrack displacement from the initial ship's track. It is measured following the first rudder reversal (feet).

b. Crosstrack Overshoot ($\% D_{OS}$) = The overshoot in distance which occurs after the rudder command is reversed (percent): $\% D_{OS} = 100 D_{OS} / D_{20}$ where $D_{OS} = D_{MAX} - D_{20}$ and D_{20} is the crosstrack

displacement when the heading change first reaches 20 degrees to the right of the initial heading.

The data in Tables H-4 and H-5 summarize the response parameters for 20/20 Z-maneuvers for the 30,000 dwt, 52,000 dwt, and 80,000 dwt tankers. These were taken from the Z-maneuver plots in Appendix E of this report and Appendix B of the Ship Variables Report. The individual parameters are grouped as turn response, heading response, and track response variables. The turn response variables are indicated in both the time domain and the distance domain.

At least one important controllability factor can be inferred from the observed results. Heading overshoot ($\% \psi_{05}$) and track response variables, often used as measures of controllability since they tell how readily the ship checks its turn, showed similar results for the 52,000 dwt and 80,000 dwt tankers. Since the performance values for the 52,000 show a proportional ship size increase over the 30,000 dwt ship, the implication is that the 80,000 dwt ship is a very good ship for its size. In piloted maneuvering situations, it would be expected that the 52,000 dwt ship would be disproportionately difficult to handle compared to the 80,000 dwt tanker. Or, in other words, the 80,000 dwt tanker would show unusually tight handling in piloted course changing and checking situations.

H.4 EVALUATION OF SHIPS MANEUVERING PERFORMANCE

The measures discussed in the two previous sections are relative measures of inherent maneuvering efficiency, but a previous study on maneuvering performance standards done for the Coast Guard,³⁶ however, might provide further insight into the absolute maneuverability of each ship for its size and offer supporting data for measuring maneuvering performance.

This earlier study measured the performance of real-world ships and divided performance into specific levels, i.e., superior, average, etc. The study derived certain non-dimensional performance measures from its extensive empirical data with the intent of setting standards for performance. Although the proposed standards are not of interest here, the measures selected to compare real-world ships can be used to assess the relative inherent controllability of the three simulated ships in their class and to see how they compare against the distribution of real ships.

One of the measures used was a non-dimensional turning parameter based on differences in tactical diameters. The formula is:

$$D' = \frac{D_T \delta_r}{35L}$$

³⁶R.A. Barr, E.R. Miller, V. Andukinov, and F.C. Lee. "Technical Basis for Maneuvering Performance Standards," U.S. Coast Guard, Washington, D.C., December 1981.

where D' is the non-dimensional turning parameter, D_T is the tactical diameter, δ_r is rudder angle, and L is the ship's length. Using this formula and the sea-trial values from Table H-1 to compare the three ships used in this experiment yields:

$$D' \text{ 30,000 dwt } = \frac{2517 \times 35}{35 \times 595} = 4.22$$

$$D' \text{ 52,000 dwt } = \frac{2391 \times 35}{35 \times 653} = 3.66$$

$$D' \text{ 80,000 dwt } = \frac{2423 \times 35}{35 \times 763} = 3.78$$

Using the empirical plots from the earlier study (Figure H-5), the 30,000 dwt ship falls into the "marginal" performance range; the 52,000 dwt ship is "below average", and the 80,000 dwt ship showed "average" performance for its size. This division of ships within displacement categories cannot be used to draw quantitative relationships among ship sizes, but they are consistent with the earlier relative measures in their implications: the 80,000 dwt ship is good for its class so may show relatively better controllability than the 52,000 dwt ship which would by the same measure be relatively better than the 30,000 dwt ship. Based on this, prior to running the experiment, it would be predicted that the differences in shiphandling performance would not be as great as these tonnages would suggest, i.e., piloted performance across all those ships would be more uniform than ship sizes would suggest: the 30,000 dwt ship would show poor performance; the performance of the 52,000 dwt ship, although it is larger, will not be as proportionally bad as the increase in tonnage would suggest. Likewise, the 80,000 dwt vessel performance will be closer to the 52,000 dwt handling than should be expected.

A second non-dimensional parameter used was based on the Z-maneuver's overshoot angle.

$$\delta^i = \frac{100 \delta_o}{\delta_r}$$

where δ_o is the overshoot angle, δ_r is the rudder angle. As shown in Figure H-6 a distinct trend of overshoot angle is evident for ships of less than 150,000. Plotting the values from Table H-4 (30K = 22, 52K = 31, 80K = 24), shows all the ships to be well within the acceptable Z-maneuver controllability. This substantiates the ship's inherent controllability as valid. Without predicting how each may do in piloted controllability situations, it implies each will be acceptably controllable.

H.5 SUMMARY OF INHERENT CONTROLLABILITY FACTORS

1. The tactical diameters predicted poorer performance for the 30,000 dwt ship than might be expected from its size and comparable performance of the 52,000 dwt and 80,000 dwt vessels.

TABLE H-1. COMPARISON OF 20/20 "Z" MANEUVERS ACROSS SHIP SIZE AND SPEED FOR 1-FOOT UNDERKEEL CLEARANCE

| | 30,000 dwt Tanker | | 52,000 dwt Tanker | | 80,000 dwt Tanker | |
|-------------------------------------------------------------|-------------------|----------|-------------------|----------|-------------------|----------|
| | 6 knots | 10 knots | 6 knots | 10 knots | 6 knots | 10 knots |
| <u>Turn Response Variables</u> | | | | | | |
| Rise time: T_{20} (seconds) | 110 | 69 | 145 | 89 | 150 | 92 |
| Heading lag: $T\Psi_{LAG}$ (seconds) | 30 | 21 | 60 | 36 | 60 | 38 |
| Displacement lag: T_{DLA} (seconds) | 160 | 101 | 260 | 168 | 260 | 168 |
| Slew rate: $\dot{\Psi}_{MAX}$ (degrees/seconds) | 0.25 | 0.40 | 0.20 | 0.34 | 0.18 | 0.30 |
| Distance traveled for T_{20} (feet) | 1097 | 1140 | 1407 | 1450 | 1476 | 1511 |
| Distance traveled to $T\Psi_{LAG}$ (feet) | 292 | 336 | 510 | 565 | 559 | 589 |
| Distance traveled for T_{DLA} (feet) | 1546 | 1601 | 2272 | 2369 | 2356 | 2527 |
| Maximum heading change per distance traveled (degrees/feet) | 0.026 | 0.025 | 0.023 | 0.024 | 0.019 | 0.015 |
| <u>Heading Response Variables</u> | | | | | | |
| Maximum heading excursion: Ψ_{MAX} (degrees) | 24.4 | 25.6 | 26.2 | 27.6 | 24.8 | 25.8 |
| Heading overshoot: $\% \Psi_{OS}$ (percent) | 22 | 28 | 31 | 38 | 24 | 29 |
| <u>Track Response Variable</u> | | | | | | |
| Maximum crosstrack excursion: D_{MAX} (feet) | 533 | 589 | 882 | 957 | 810 | 865 |
| Crosstrack overshoot: $\% D_{OS}$ (percent) | 330 | 367 | 495 | 573 | 459 | 492 |

TABLE H-2. COMPARISON OF 20/20 Z MANEUVERS ACROSS SHIP SIZE AND UNDERKEEL CLEARANCE FOR SHIP'S SPEED OF 6 KNOTS

| | 30,000 dwt Tanker (feet underkeel) | | 52,000 dwt Tanker (feet underkeel) | | 80,000 dwt Tanker (feet underkeel) | |
|----------------------------------------------------------------|---------------------------------------|-------|---------------------------------------|-------|---------------------------------------|-------|
| | 1 | 600 | 1 | 600 | 1 | 600 |
| <u>Turn Response Variables</u> | | | | | | |
| Rise time: T_{20} (seconds) | 110 | 93 | 145 | 140 | 150 | 125 |
| Heading lag: $T\Psi_{LAG}$ (seconds) | 30 | 40 | 60 | 120 | 60 | 75 |
| Displacement lag: T_{DLAG} (seconds) | 160 | 160 | 260 | 380 | 260 | 300 |
| Slew rate: $\dot{\Psi}_{MAX}$ (degrees/seconds) | 0.25 | 0.31 | 0.20 | 0.23 | 0.18 | 0.25 |
| Distance traveled for T_{20} (feet) | 1097 | 950 | 1407 | 1387 | 1476 | 1253 |
| Distance traveled for $T\Psi_{LAG}$ (feet) | 292 | 406 | 510 | 1037 | 559 | 708 |
| Distance traveled for T_{DLAG} (feet) | 1546 | 1646 | 2272 | 3203 | 2356 | 2784 |
| Maximum heading change per distance traveled (degrees/feet) | 0.026 | 0.030 | 0.023 | 0.027 | 0.019 | 0.025 |
| <u>Heading Response Variables</u> | | | | | | |
| Maximum heading excursion: Ψ_{MAX} (degrees) | 24.4 | 25.9 | 26.2 | 30.8 | 24.8 | 28.7 |
| Heading overshoot: $\% \Psi_{OS}$ (percent) | 22 | 30 | 31 | 54 | 24 | 44 |
| <u>Track Response Variable</u> | | | | | | |
| Maximum crosstrack excursion: D_{MAX} (feet) | 533 | 523 | 882 | 1343 | 810 | 940 |
| Crosstrack overshoot: $\% D_{OS}$ (percent) | 330 | 545 | 495 | 1413 | 459 | 1100 |

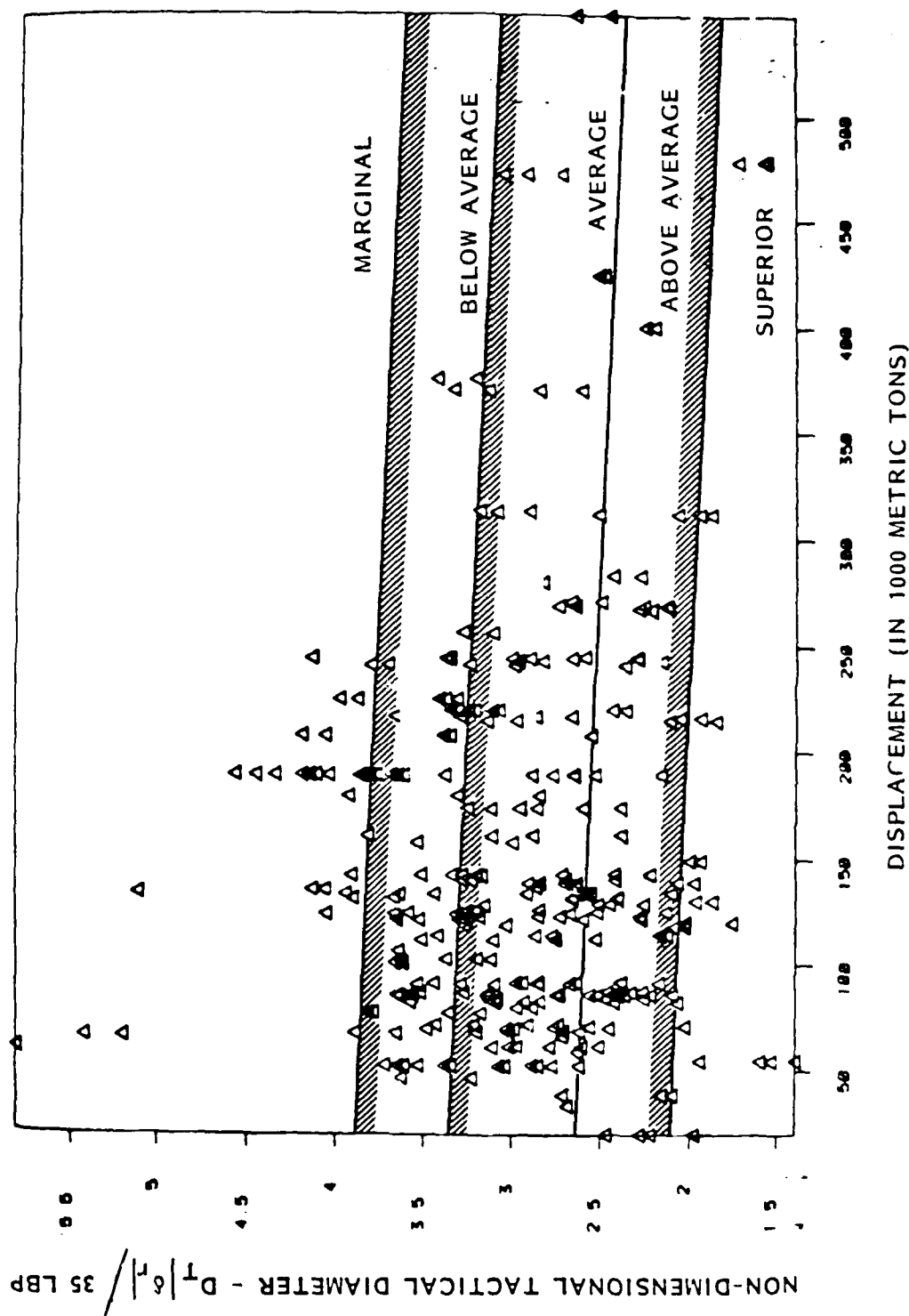


Figure II-5. Performance Ratings Based on Tanker Tactical Diameter
 Source: "Technical Basis for Maneuvering Performance Standards," December, 1981.

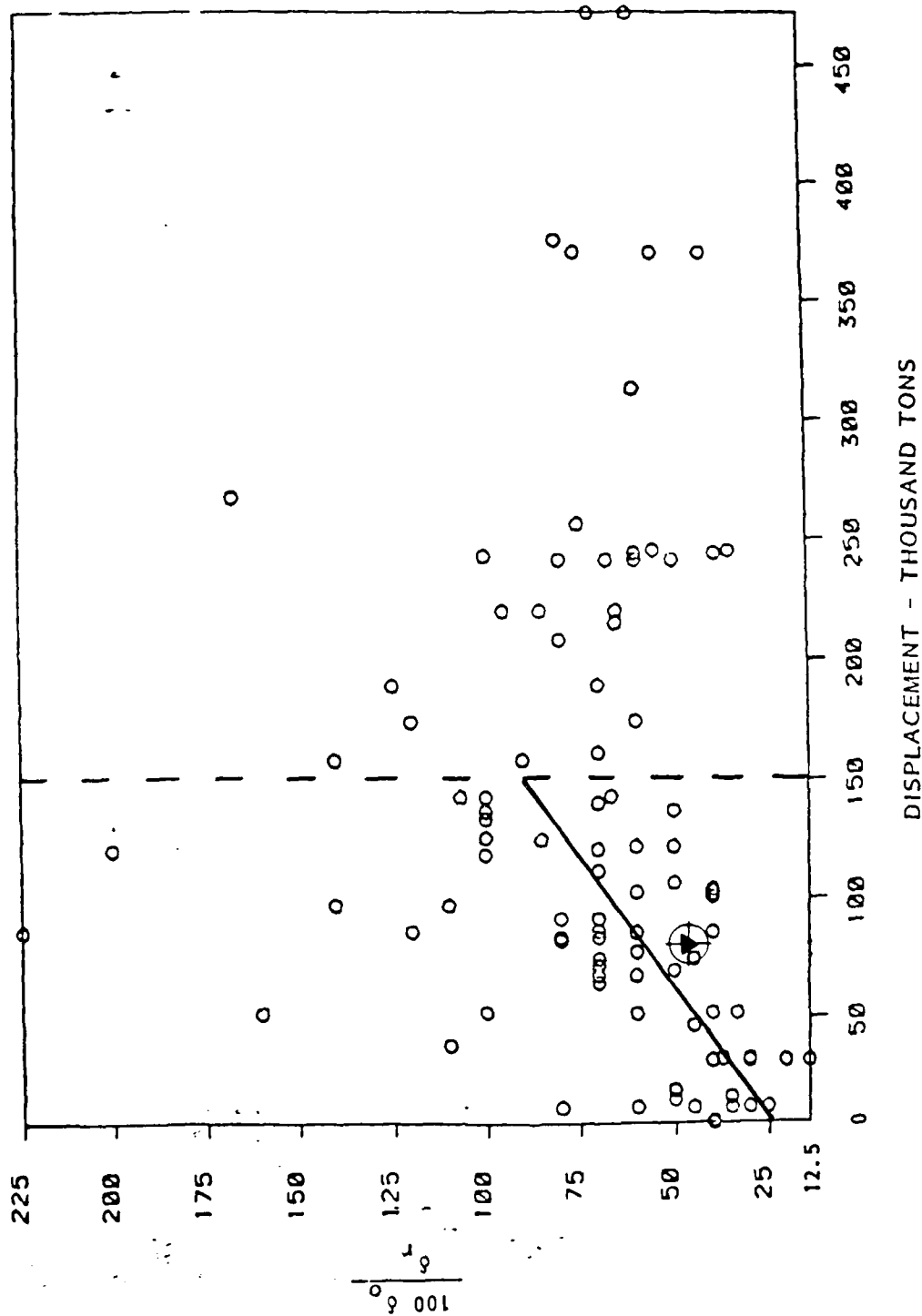


Figure H-6. Non-Dimensional Overshoot Angles From Ziq-Zag Maneuvers
 Source: "Technical Basis for Maneuvering Performance Standards," December, 1981.

2. The Z-maneuver values predict the 80,000 dwt ship will be a very tight handling vessel for its size with turning/checking performance close to the 52,000 dwt ship.

3. The non-dimensional parameters correlate well with the sea-trial tests showing the 30,000 dwt ship to have marginal controllability for its size, the 52,000 dwt ship to be below average, and the 80,000 dwt ship to be average. It is not possible to quantify these performances across ship sizes (displacement tonnages) but it would imply as above that the 30,000 dwt vessel would exhibit the worst handling and the 80,000 dwt tanker the best performance.

H.6 RELATIONSHIP TO PILOTED CONTROLLABILITY

None of these predictions were supported, however. The truest indicator of performance was the ship's displacement tonnage. Piloted controllability, based on these simulated ships and scenarios, declined as deadweight tonnage increased. The conclusion this prompts is that ship correction factors should be based on deadweight tonnage, as they have been in the Design Manual.

Appendix I
SPEED EFFECTS ON INHERENT CONTROLLABILITY

I.1 COMPARISON OF DIFFERENT SPEEDS

This appendix contains an analysis and ship response data to examine speed-related differences among the 30,000, 52,000 and 80,000 dwt ships that were simulated in this experiment. The object of the comparisons is to determine how the ship's speed affects its inherent controllability and what these results might imply for piloted controllability.

Intuitively it would seem that a speed increase would increase controllability since the "wash" over the ship's rudder would increase. The ship would be more responsive as the speed is increased; equal amounts of rudder would result in quicker changes in heading. Or, from a different perspective, less rudder would be necessary to effect course changes as the speed increases. However, increased speed also reduces the time in which the pilot has to respond introducing a negative factor to the piloted controllability equation. (See Appendix H for turning circle and Z-maneuver plots.)

From the sea trial data shown in Tables I-1 and I-2, it is not immediately apparent whether speed will be a positive or negative factor in controllability. The turning circle results, Table I-1, show no meaningful differences in inherent measures for each ship at the different speeds. Results of the 20/20 Z-maneuvers, shown in Table I-2, do provide some relevant information.

TABLE I-1. COMPARISON OF TURN CIRCLES ACROSS SHIP SIZE AND SPEED
WITH 1-FOOT UNDERKEEL CLEARANCE

| Ship Size | 30,000 dwt | | 52,000 dwt | | 80,000 dwt | |
|--------------------------|------------|------|------------|------|------------|------|
| Speed (knots) | 6 | 10 | 6 | 10 | 6 | 10 |
| Tactical diameter (feet) | 3625 | 3657 | 3243 | 3245 | 3753 | 3760 |
| Advance (feet) | 2114 | 2192 | 2298 | 2342 | 2496 | 2558 |
| Transfer (feet) | 1700 | 1811 | 1585 | 1580 | 1790 | 1958 |

Examining the speed changes on a ship-by-ship basis, Table I-2 shows that the track, heading, and turn response measured in distance are relatively unchanged. The speed increase does, however, affect the variables in the time domain. Since the ship reaction times drop substantially in the speed change from 6 to 10 knots, the implication is, as noted above, that less rudder could be used to effect the same maneuver or rudder taken off sooner to effect equivalent maneuvers in piloted controllability situation.

TABLE 1-2. COMPARISON OF 20/20 "Z" MANEUVERS ACROSS SHIP SIZE AND SPEED FOR 1-FOOT UNDERKEEL CLEARANCE

| | 30,000 dwt Tanker | | 52,000 dwt Tanker | | 80,000 dwt Tanker | |
|-------------------------------------------------------------|-------------------|----------|-------------------|----------|-------------------|----------|
| | 6 knots | 10 knots | 6 knots | 10 knots | 6 knots | 10 knots |
| <u>Turn Response Variables</u> | | | | | | |
| Rise time: T_{20} (seconds) | 110 | 69 | 145 | 89 | 150 | 92 |
| Heading lag: $T\psi_{LAG}$ (seconds) | 30 | 21 | 60 | 36 | 60 | 38 |
| Displacement lag: T_{DLAG} (seconds) | 160 | 101 | 260 | 168 | 260 | 168 |
| Slew rate: $\dot{\psi}_{MAX}$ (degrees/seconds) | 0.25 | 0.40 | 0.20 | 0.34 | 0.18 | 0.30 |
| Distance traveled for T_{20} (feet) | 1097 | 1140 | 1407 | 1450 | 1476 | 1511 |
| Distance traveled to $T\psi_{LAG}$ (feet) | 292 | 336 | 510 | 565 | 559 | 589 |
| Distance traveled for T_{DLAG} (feet) | 1546 | 1601 | 2272 | 2369 | 2356 | 2527 |
| Maximum heading change per distance traveled (degrees/feet) | 0.026 | 0.025 | 0.023 | 0.024 | 0.019 | 0.019 |
| <u>Heading Response Variables</u> | | | | | | |
| Maximum heading excursion: ψ_{MAX} (degrees) | 24.4 | 25.6 | 26.2 | 27.6 | 24.8 | 25.8 |
| Heading overshoot: $\% \psi_{OS}$ (percent) | 22 | 28 | 31 | 38 | 24 | 29 |
| <u>Track Response Variable</u> | | | | | | |
| Maximum crosstrack excursion: D_{MAX} (feet) | 533 | 589 | 882 | 957 | 810 | 865 |
| Crosstrack overshoot: $\% D_{OS}$ (percent) | 330 | 367 | 495 | 573 | 459 | 492 |

I.2 SUMMARY OF INHERENT CONTROLLABILITY FACTORS

1. The turning circles results predict no change in performance with the change in speed from 6 to 10 knots for any of the ships.

2. The track, heading, and turn response measures from the Z-maneuvers are relatively unchanged for each ship. (Since pilots rely primarily on distance cues, primarily buoy positions, piloted controllability for each of these ships at different speeds would be expected to be similar if sufficient distance cues were provided at different speeds. This might imply more cues (buoys) would be necessary at higher speeds.)

3. The time domain measures from the Z-maneuvers predict that the ship will show similar performance at the two speeds with less rudder used, or equal amounts of rudder held for less time.

I.3 RELATIONSHIP TO PILOTED CONTROLLABILITY

The piloted controllability scenarios from this experiment bore out the implications of the inherent controllability results. Performance was essentially the same in the case of the 30,000 dwt and 52,000 dwt ships, and even slightly improved due to increased responsiveness. The 80,000 dwt ship needed additional distance cues (high buoy density) to show the equivalent performance at higher speeds.

Appendix J
SHIP RESPONSE DATA FOR THE 52,000 DWT SHIP

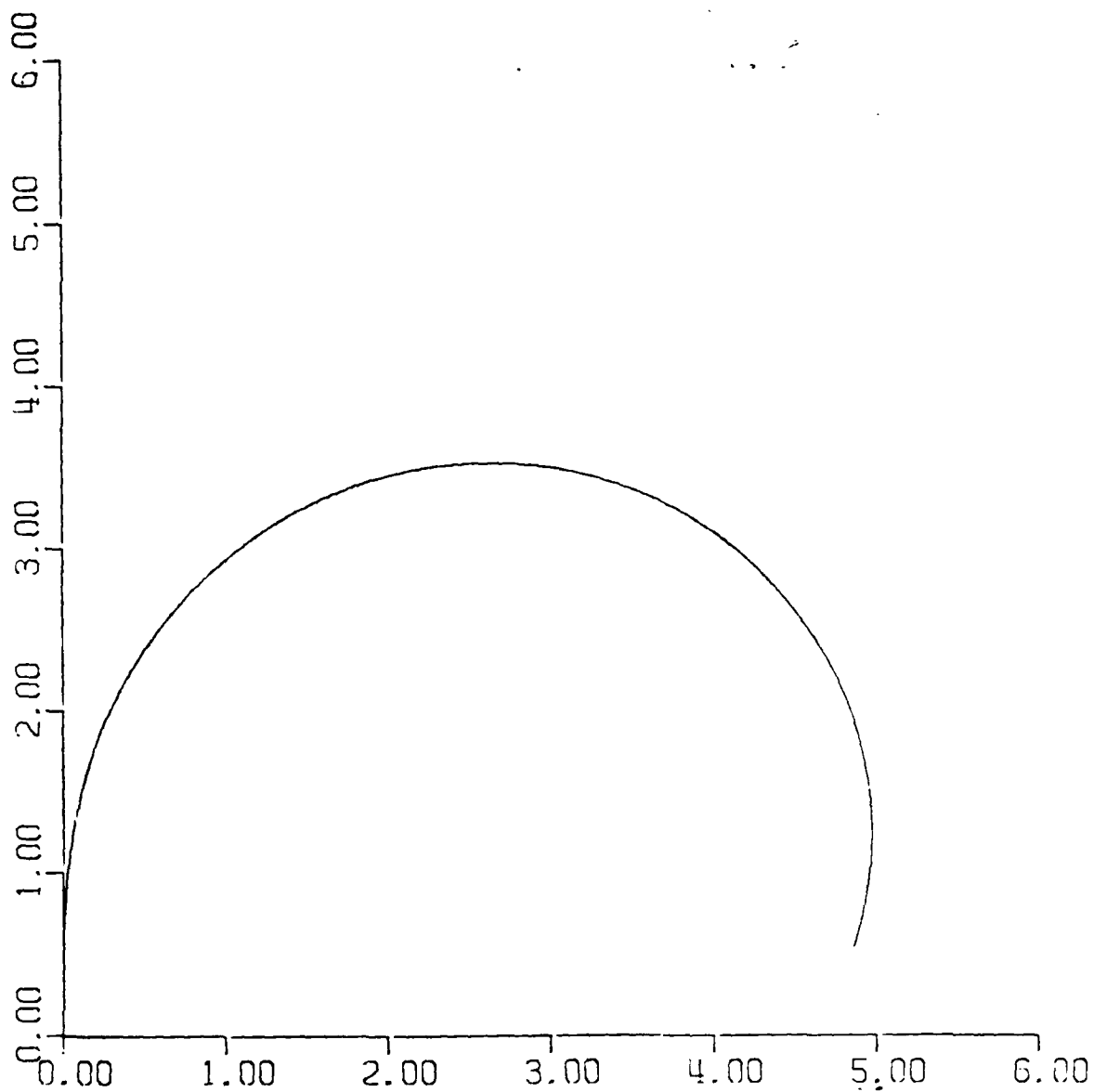
This appendix contains plots of ship's tracks and response data recorded during simulated sea trial maneuvers. Turning circles and Z-maneuvers were evaluated. Data for the 52,000 dwt ship are included in this appendix. Data for the 30,000 and 80,000 dwt ships are included in Appendix B of the Ship Variables Principal Findings Report. Trial maneuvers were conducted under the following conditions: speed was at either 6 or 10 knots and underkeel clearance was at 1 foot or >600 feet. The figure contents are listed below.

Turning Maneuvers

- Figure J-1: 52K - 35 Degree Turn Circle - 1 foot underkeel - 6 knots
- Figure J-2: 52K - 35 Degree Turn Circle - 1 foot underkeel - 10 knots
- Figure J-3: 52K - 35 Degree Turn Circle - 10 foot underkeel - 6 knots
- Figure J-4: 52K - 35 Degree Turn Circle - 600 foot underkeel - 6 knots
- Figure J-5: 52K - 20 Degree Turn Circle - 1 foot underkeel - 6 knots

20/20 Z-Maneuvers

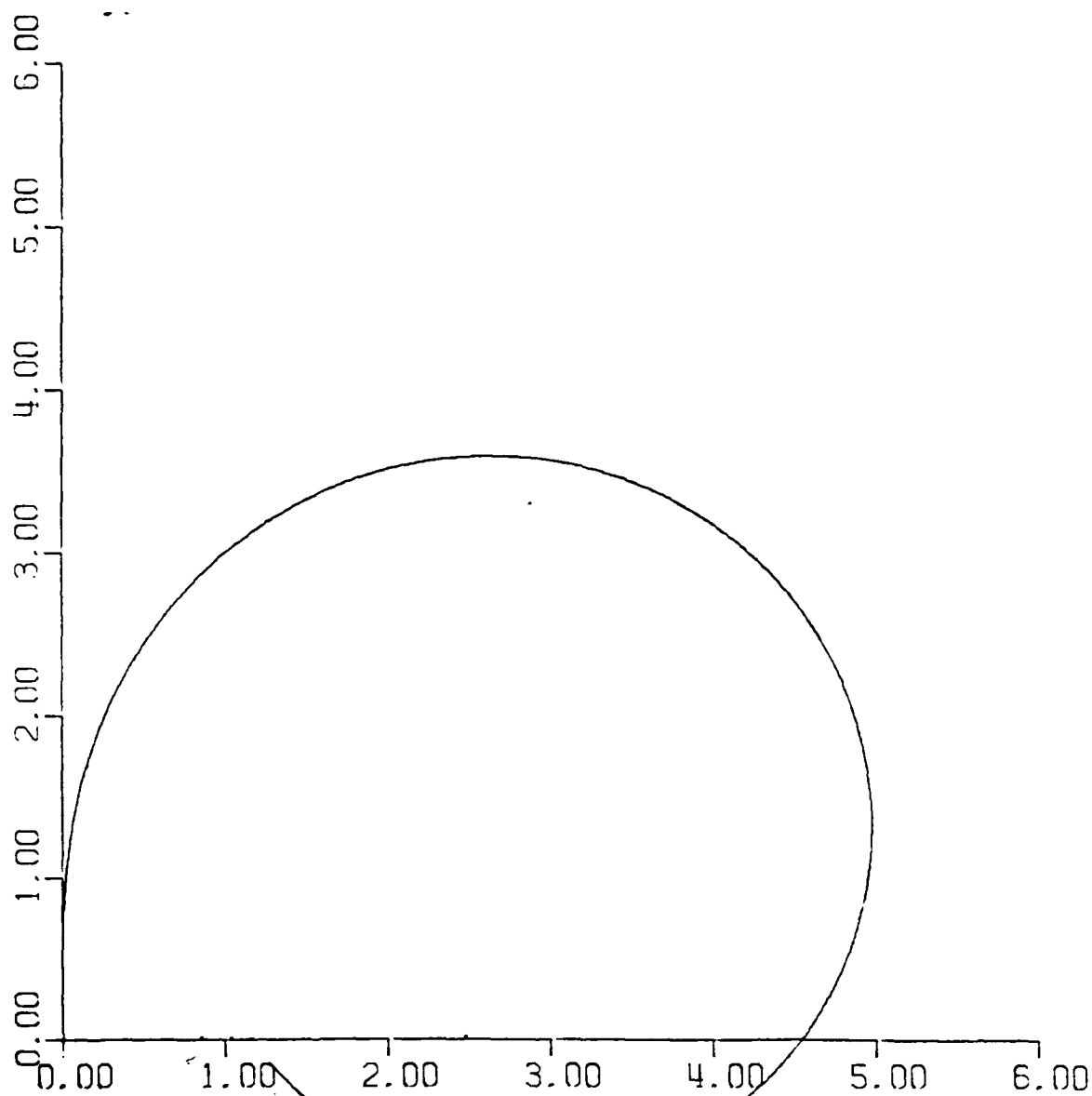
- Figure J-6: 52K - Heading Response - 6 knots - 1 foot underkeel
- Figure J-7: 52K - Track Response - 6 knots - 1 foot underkeel
- Figure J-8: 52K - Heading Response - 10 knots - 1 foot underkeel
- Figure J-9: 52K - Track Response - 10 knots - 1 foot underkeel
- Figure J-10: 52K - Heading Response - 6 knots - 10 foot underkeel
- Figure J-11: 52K - Track Response - 6 knots - 10 foot underkeel
- Figure J-12: 52K - Heading Response - 6 knots - 600 foot underkeel
- Figure J-13: 52K - Track Response - 6 knots - 600 foot underkeel
- Figure J-14: 52K - Track Response - 6 knots - 600 foot underkeel
- Figure J-15: 52K - Track Response - 10 knots - 10 foot underkeel



52K - 35 DEGREE TURN CIRCLE -- 1 FT UNDER KEEL -- 6 KNOTS

SCALE -- 653.0 FEET / INCH

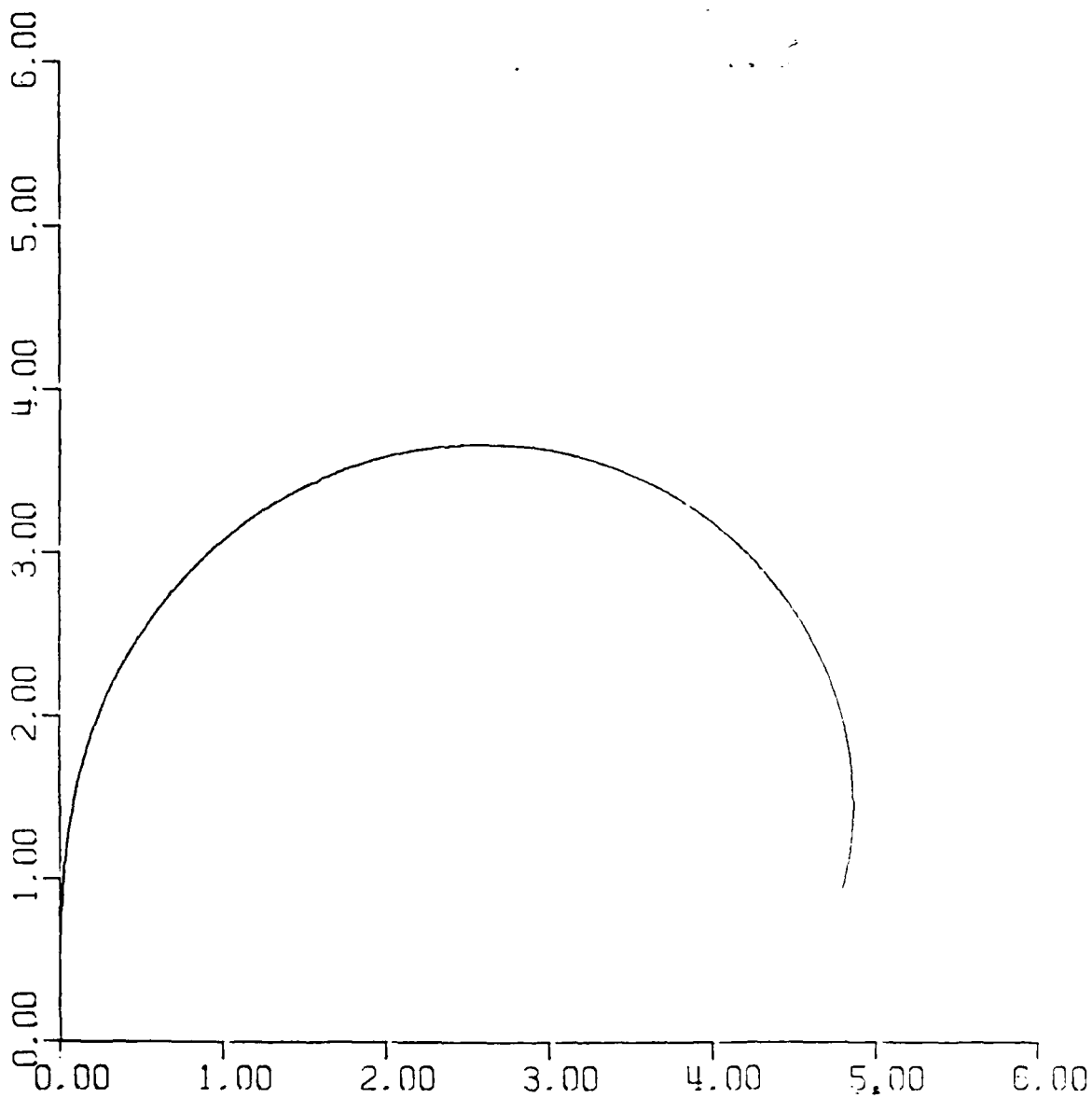
Figure J-1



52K - 35 DEGREE TURN CIRCLE - 1 FT UNDER KEEL - 10 KNOTS

SCALE -- 653.0 FEET / INCH

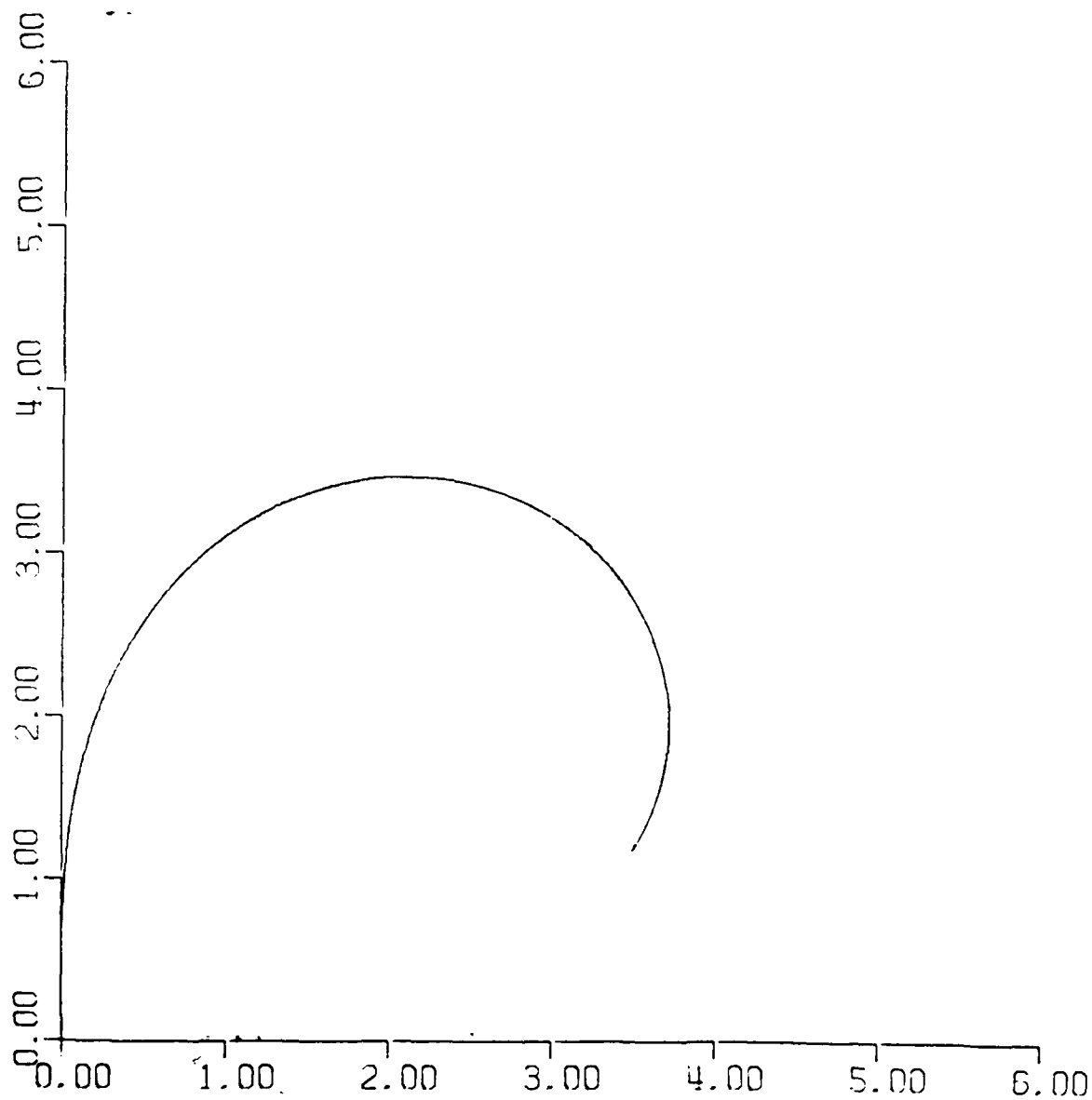
Figure J-2



52K - 35 DEGREE TURN CIRCLE -- 10 FT UNDER KEEL -- 6 KNOTS

SCALE -- 653.0 FEET / INCH

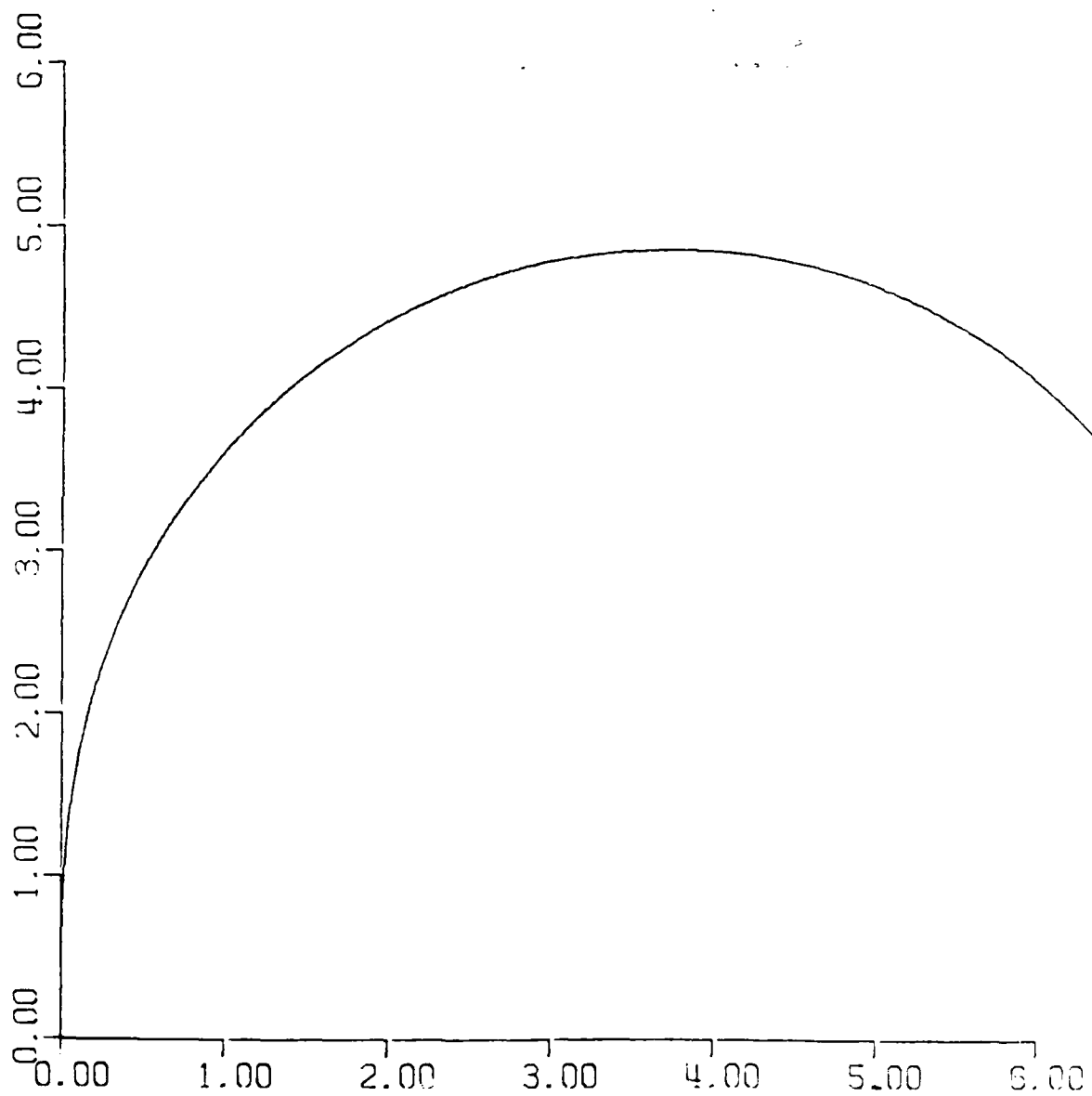
Figure J-3



52K - 35 DEGREE TURN CIRCLE -- 600 FT UNDER KEEL - 6 KNOTS

SCALE -- 653.0 FEET / INCH

Figure J-4

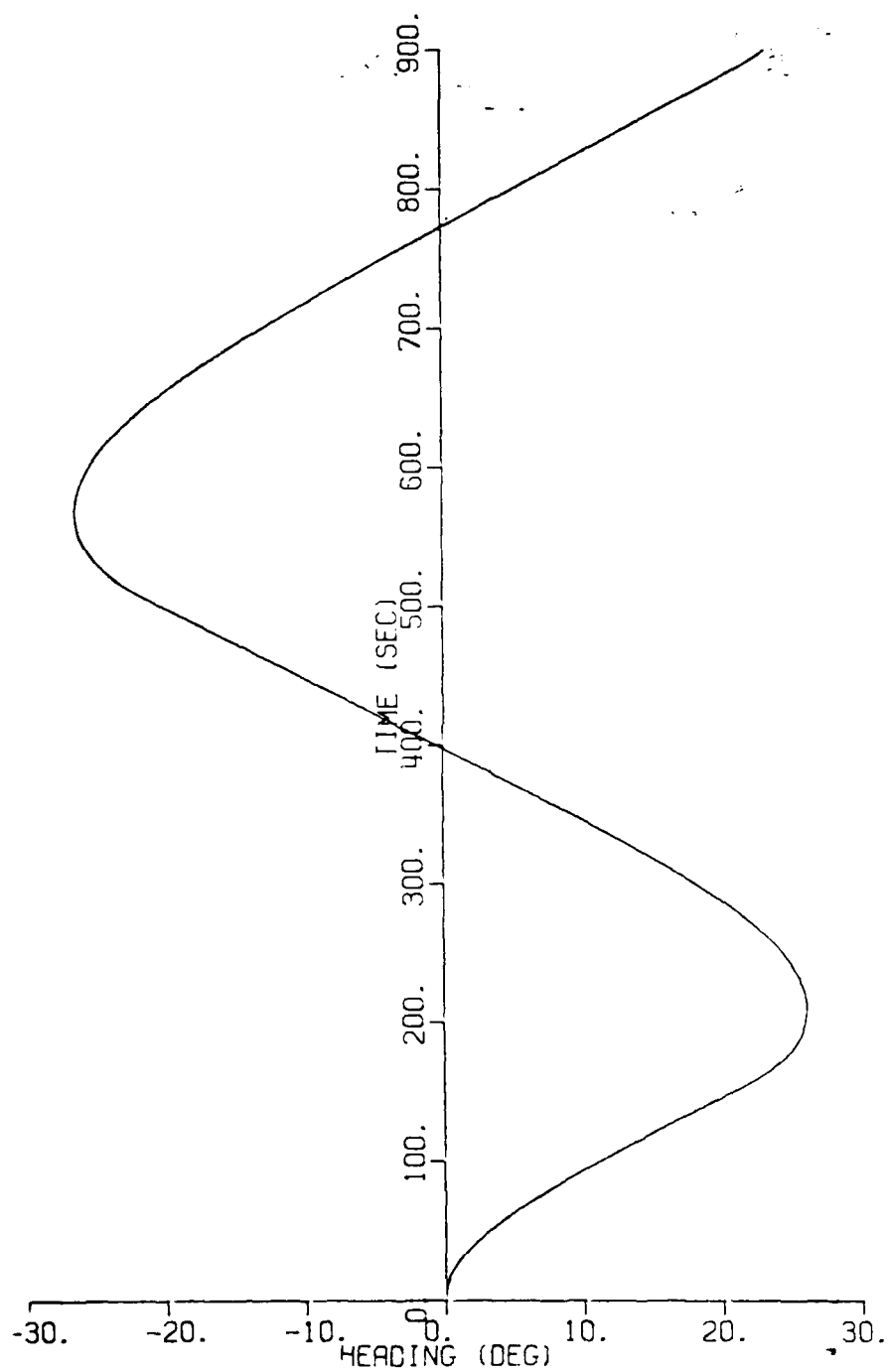


52K - 20 DEGREE TURN CIRCLE - 1 FT UNDER KEEL - 6 KNOTS*

SCALE -- 653.0 FEET / INCH

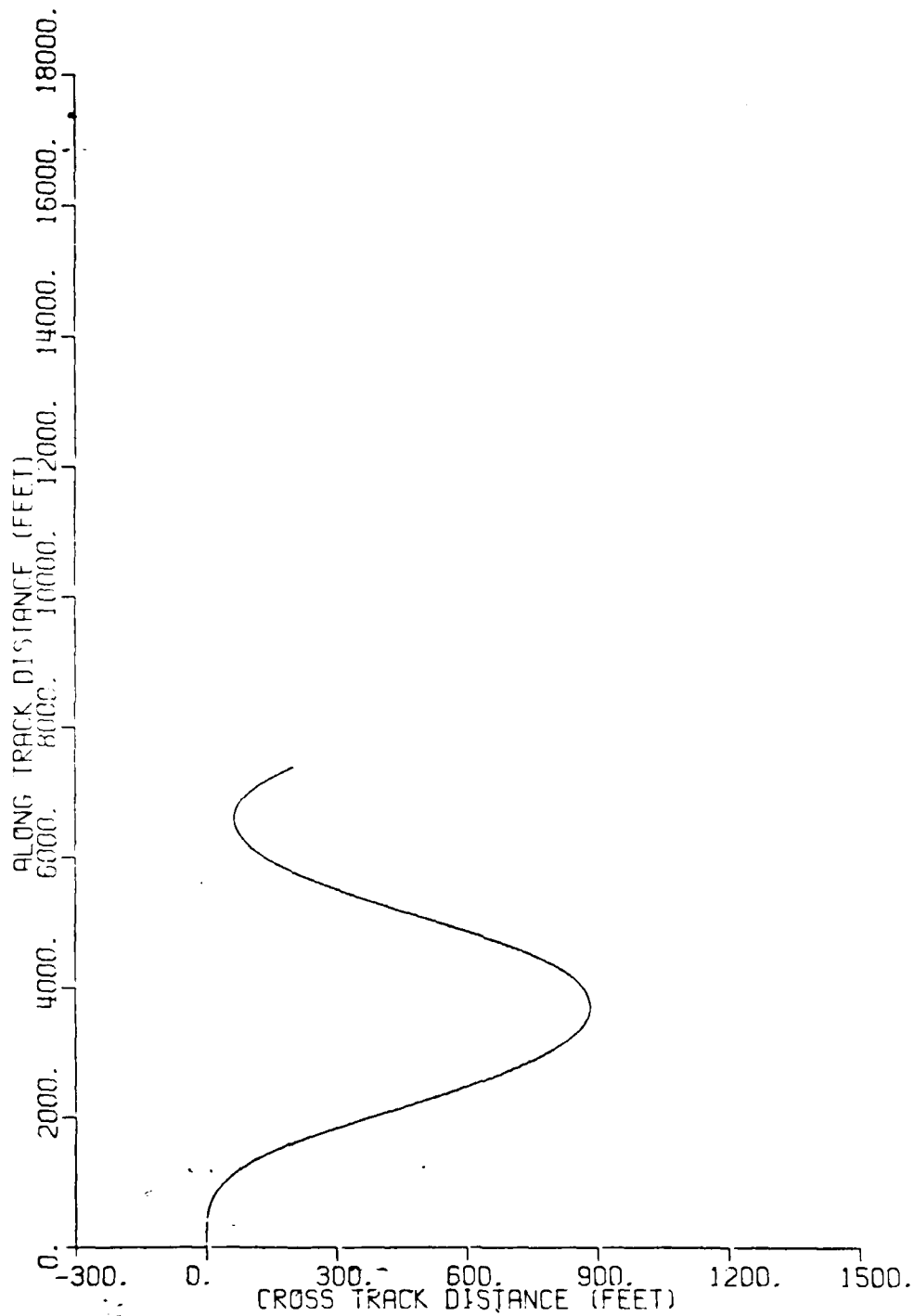
Figure J-5

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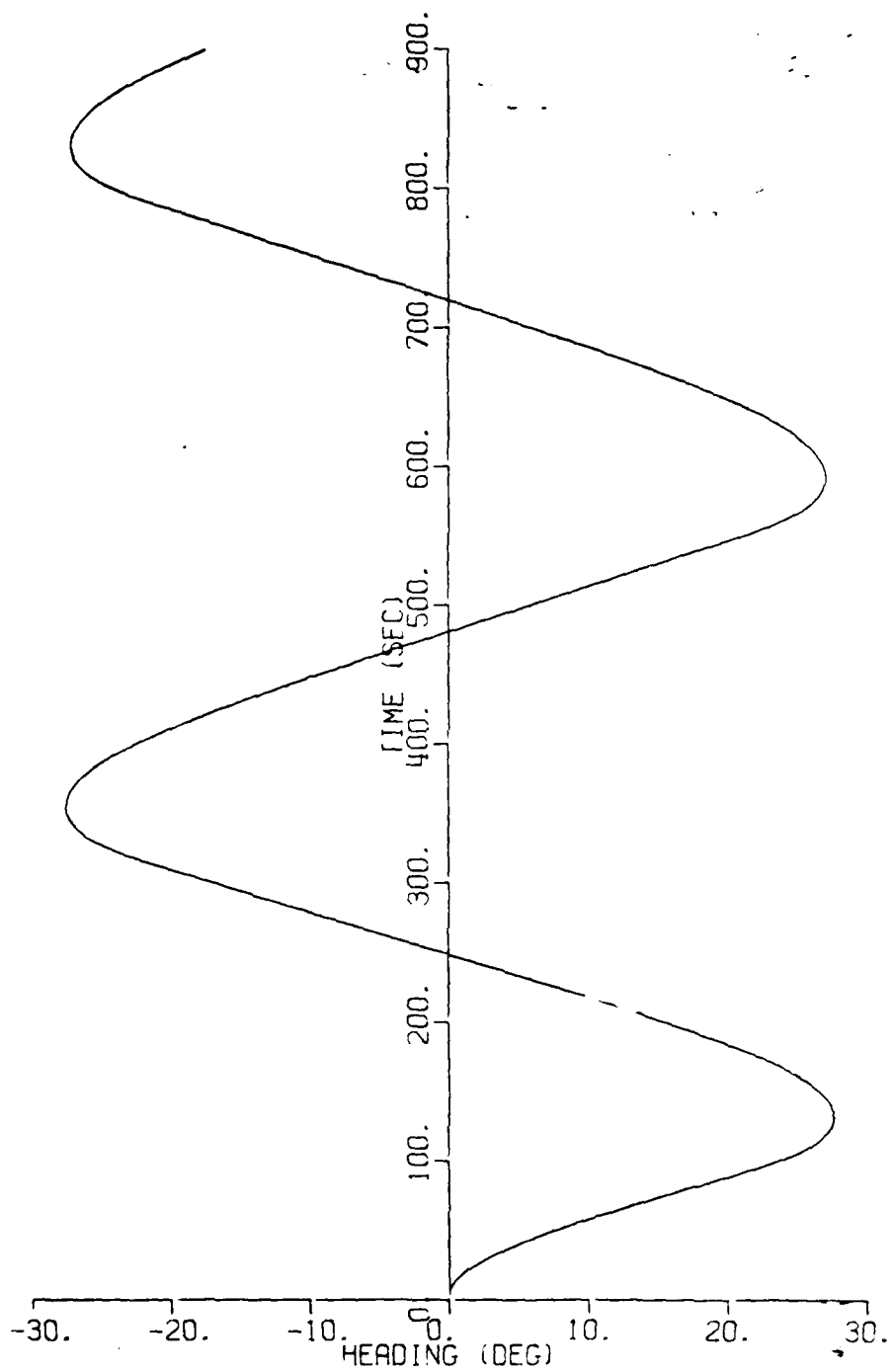
52K - 20 DEG. Z MANEUVER - HEADING RESPONSE - 1 FT UNDER KEEL - 6 KTS

Figure J-6



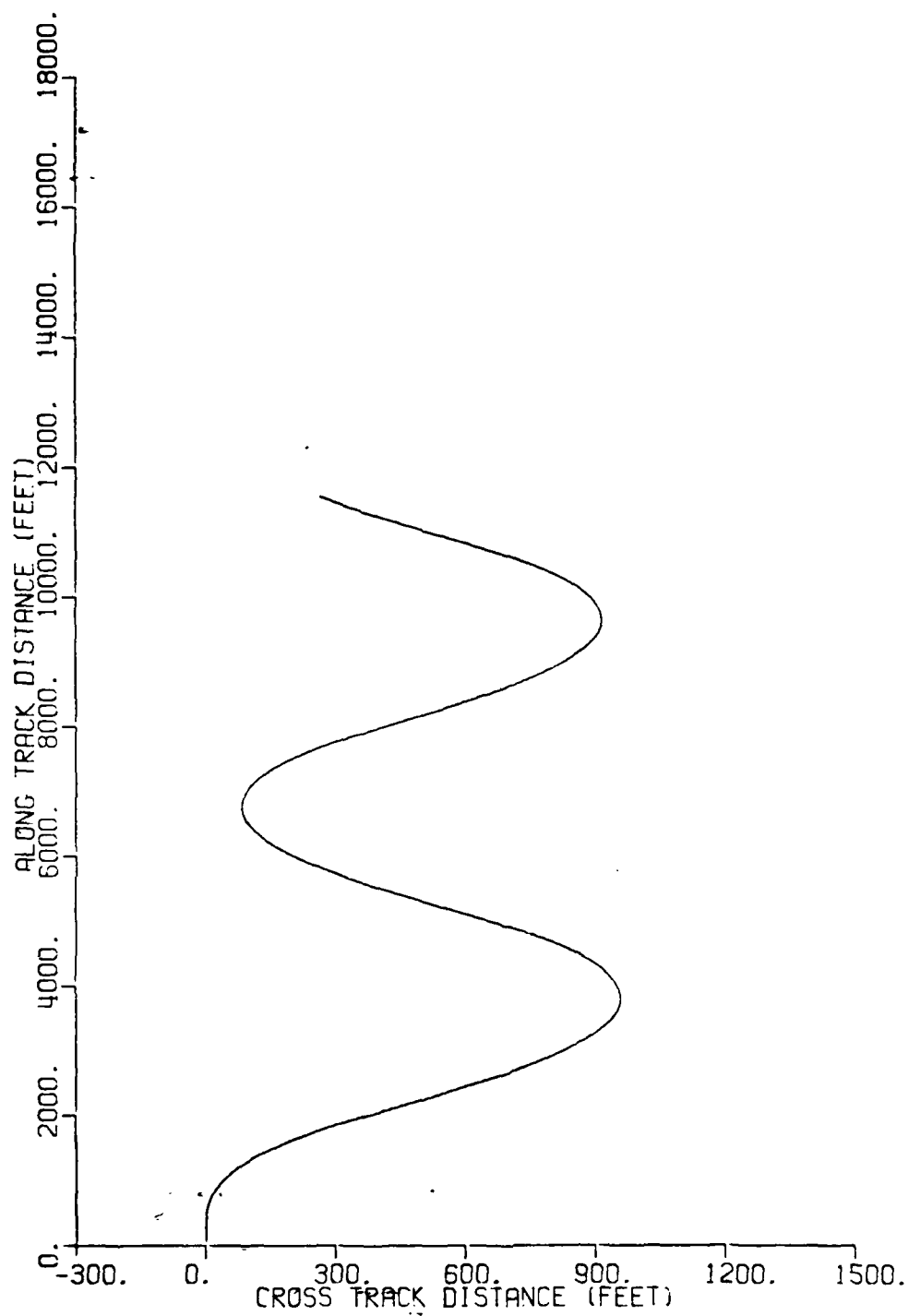
52K - 20 DEG. Z MANEUVER - TRACK RESPONSE - 1 FT UNDER KEEL - 6 KTS

Figure J-7



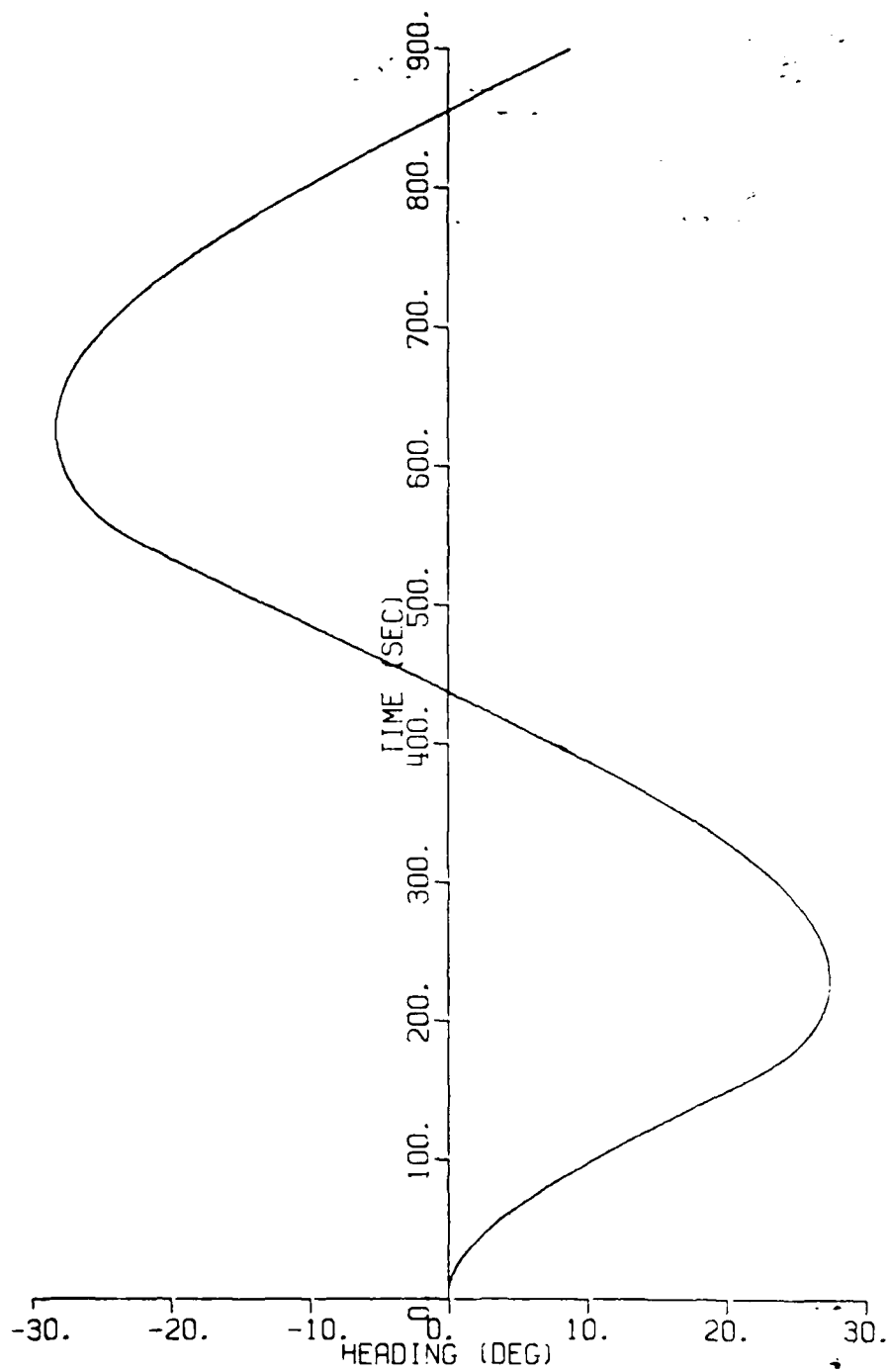
52K - 20 DEG. Z MANEUVER - HEADING RESPONSE - 1 FT UNDER KEEL - 10 KTS

Figure J-8



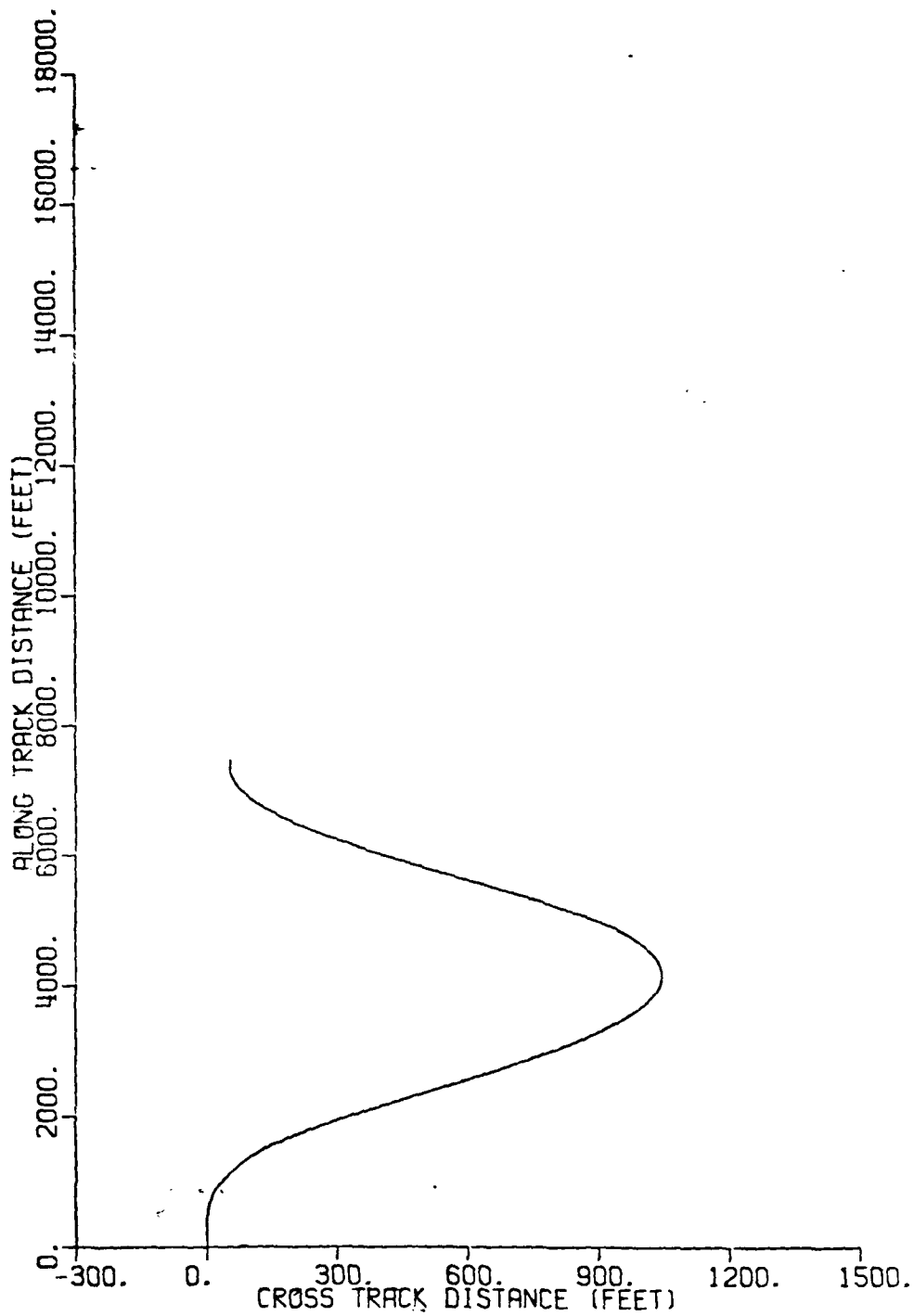
92K - 20 DEG. Z MANEUVER - TRACK RESPONSE - 1 FT UNDER KEEL - 10 KTS

Figure J-9



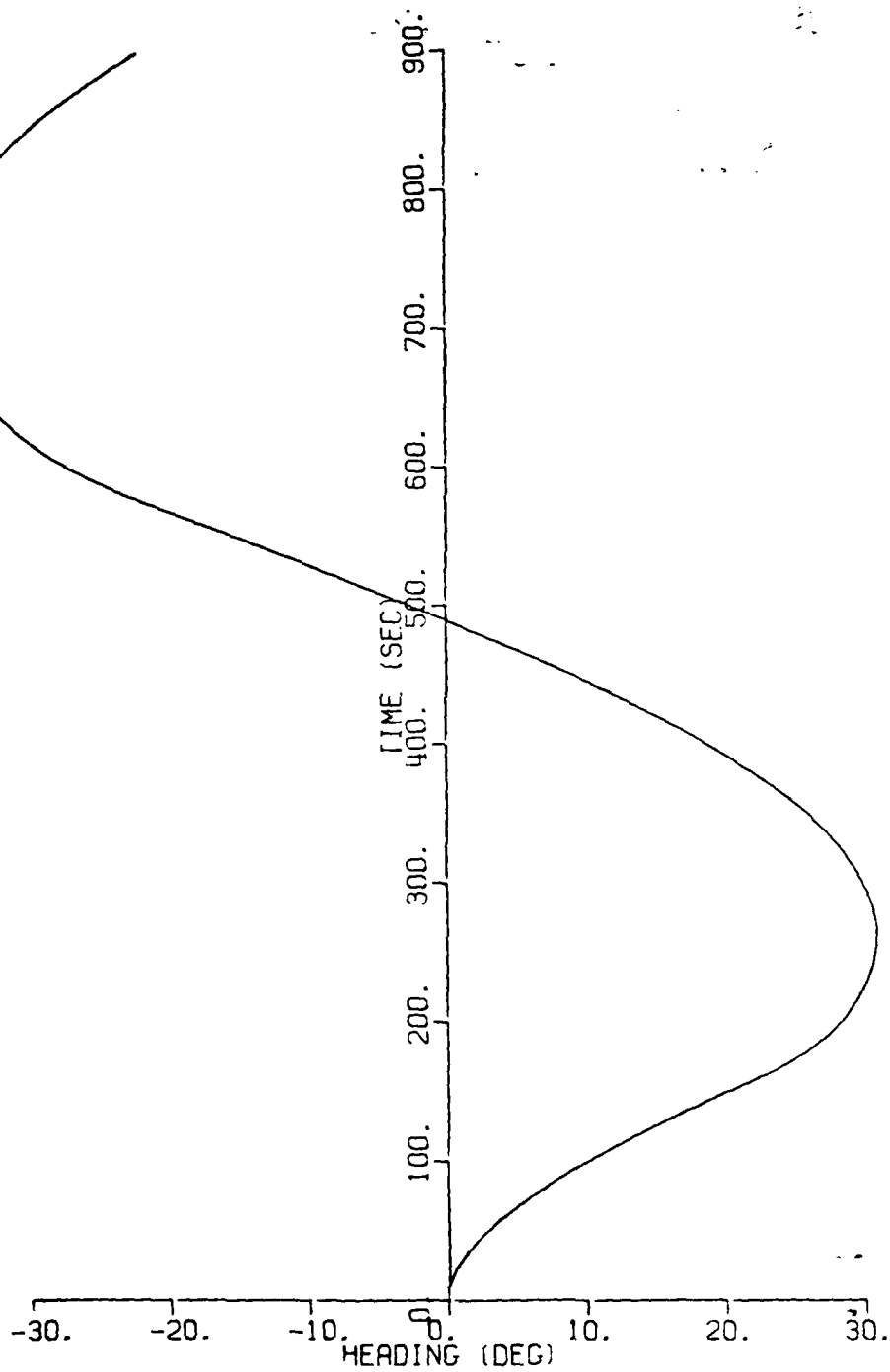
52K - 20 DEG. Z MANUEVER - HEADING RESPONSE- 10 FT UNDER KEEL - 6 KTS

Figure J-10



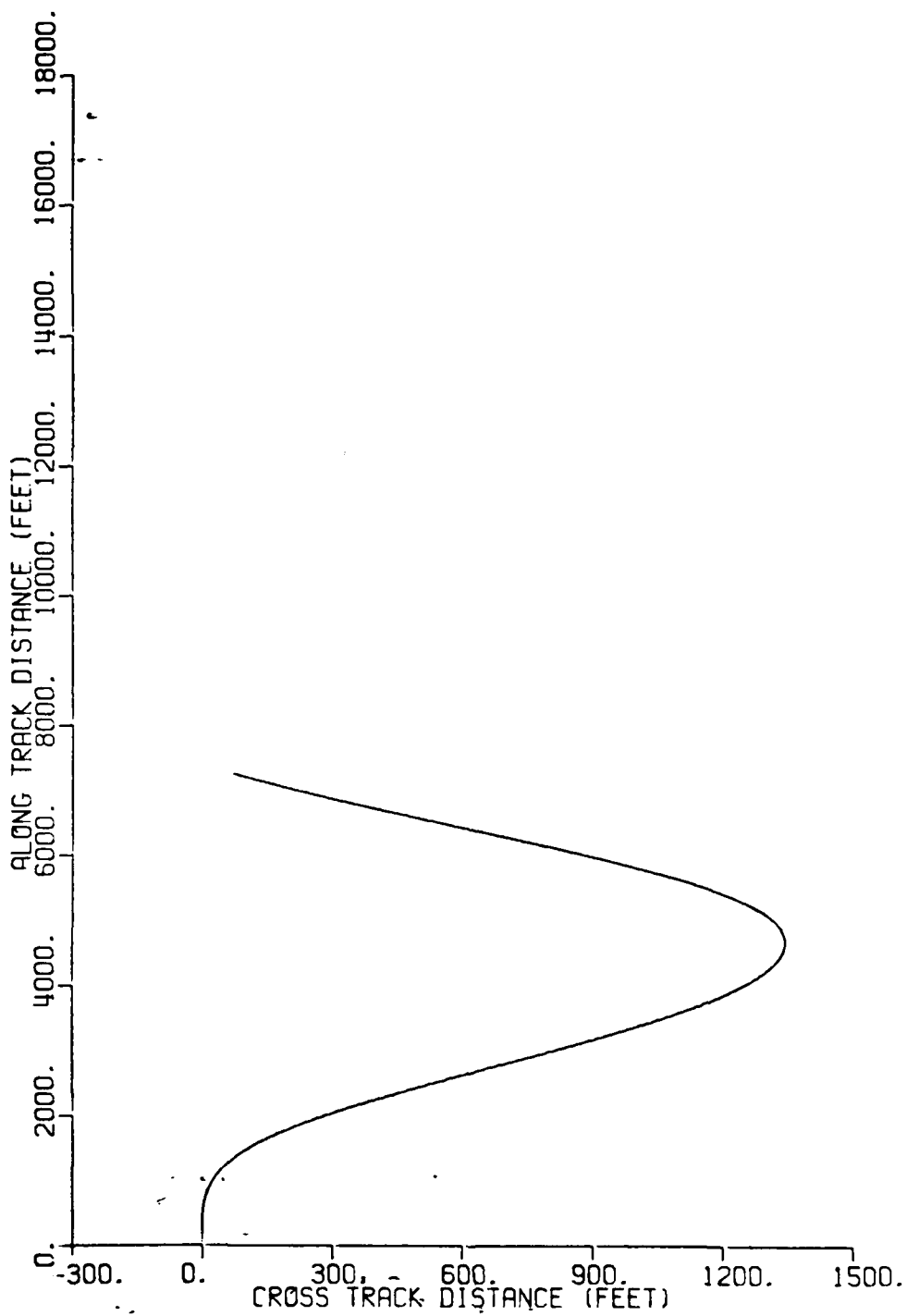
52K - 20 DEG. Z MANUEVER - TRACK RESPONSE- 10 FT UNDER KEEL - 6 KTS

Figure J-11



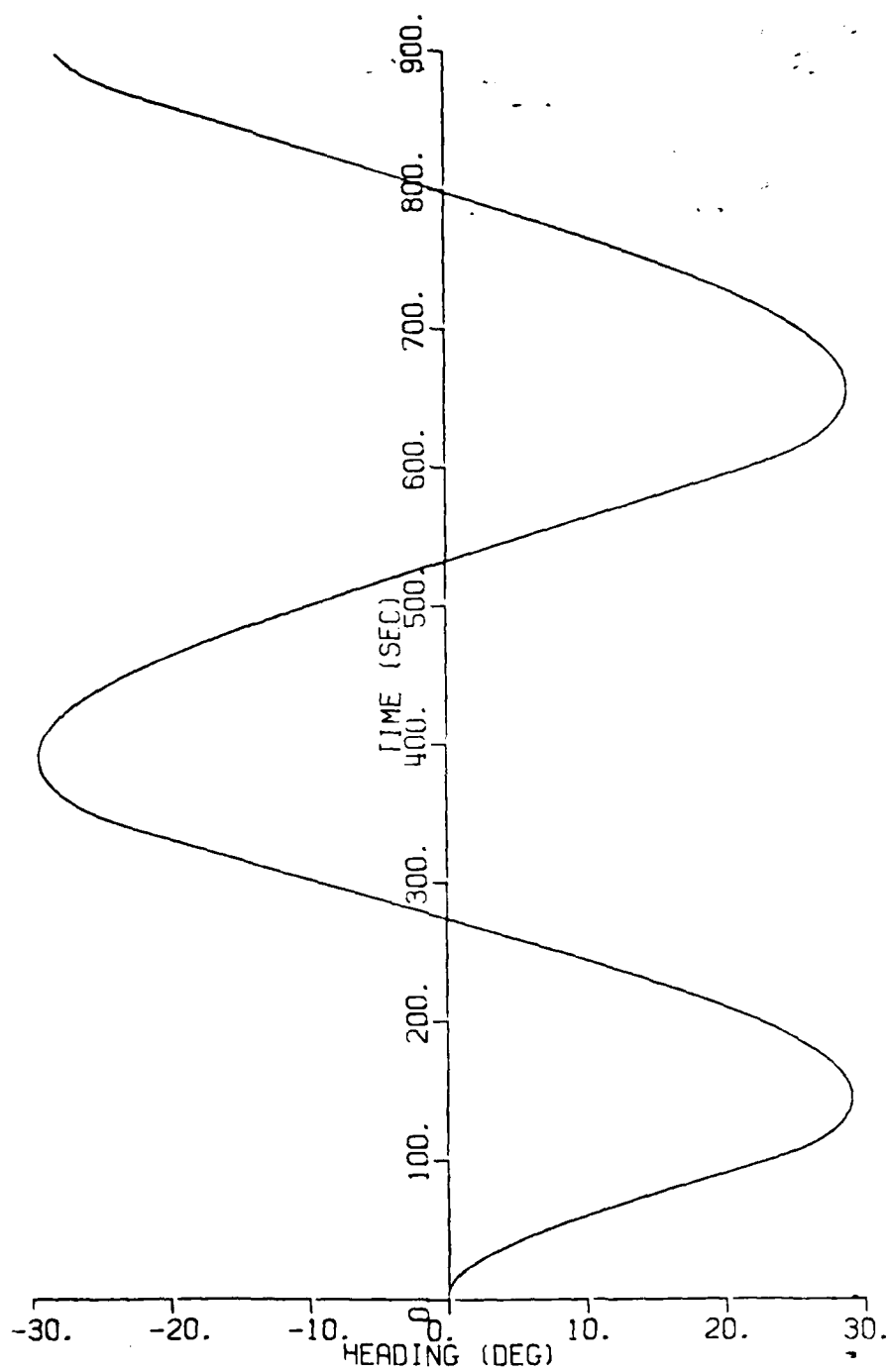
52K - 20 DEG. Z MANEUVER -HEADING RESPONSE- 600 FT UNDER KEEL - 6 KTS

Figure J-12



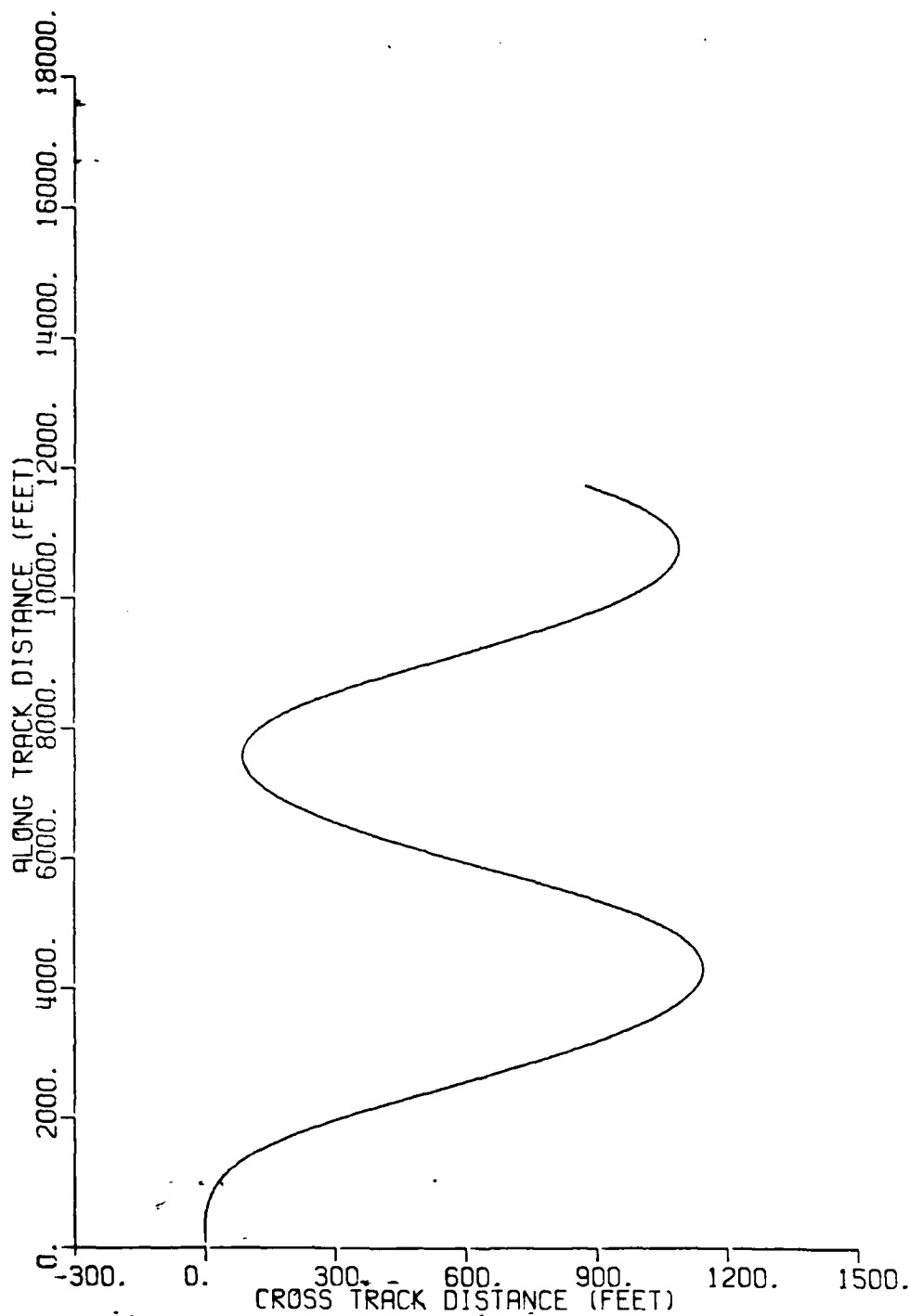
52K - 20 DEG, Z MANUEVER - TRACK RESPONSE - 600 FT UNDER KEEL - 6 KTS

Figure J-13



52K - 20 DEG. Z MANUEVER - HEADING RESPONSE - 10 FT UNDER KEEL - 10 KTS

Figure J-14



52K - 23 DEG. Z MANUEVER - TRACK RESPONSE - 10 FT UNDER KEEL - 10 KTS
Figure J-15

GLOSSARY

The following acronyms and specialized terms are defined here as they are used in this report.

- AN aids to navigation, used to describe the project of which the present experiment is a part. See the preface and page 1.
- CAORF Computer Aided Operations Research Facility, the Maritime Administration's simulator at Kings Point, New York; used as a short title from an earlier experiment run there and referenced in the preface.
- CW Channel Width, used as a short title for an earlier experiment referenced on page 33.
- dwt dead weight ton, the difference between the loaded and light displacement of a vessel.
- nm nautical mile, 6076 feet.
- OS One Side Channel Marking, used as a short title for an earlier report referenced on page 20.
- RA Radio Aids, used to refer to an earlier series of experiments on Loran C piloting. Data from those experiments was included in the 1962 draft manual referenced on page 1.
- RI Radar I, used as a short title for an earlier experiment referenced on page 1.
- RRF relative risk factor, a performance measure, the probability of grounding under specified conditions. See Section 2.2.
- SRA Short Range Aids, used generally to refer to a series of experiments in visual piloting with buoys and ranges; also used as a short title for the present experiment.
- SV Ship Variables, used to refer to an earlier experiment reference on page 22.
- TL Turn Lights, used as a short title for an experiment reference on page 1.

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